Human Capital, Economic Growth, and Regional Inequality in China*

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Abstract

We show how regional growth patterns in China depend on physical,, human, and infrastructure capital; foreign direct investment (FDI); and market reforms, especially the reforms that followed Deng Xiaoping's "South Trip" in 1992 those that resulted from serious hardening of budget constraints of state enterprises around 1997. We find that FDI had a much larger effect on TFP growth before 1994 than after, and we attribute this to the encouragement of and increasing success of private and quasi-private enterprises. We find that human capital positively affects output per worker and productivity growth in our cross-provincial study. Moreover, we find both direct and indirect effects of human capital on TFP growth. The direct effect is hypothesized to come from domestic innovation activities, while the indirect impact is a spillover effect of human capital on TFP growth. We conduct cost-benefit analysis of hypothetical investments in human capital and infrastructure. We find that, while investment in infrastructure generates higher returns in the developed, eastern regions than in the interior, investing in human capital generates slightly higher or comparable returns in the interior regions. We conclude that human capital investment in less-developed areas can improve economic efficiency, neither investment strategy is a magic bullet for reducing China's regional income disparities.

JEL Codes: O15 O18 O47 O53

1. Introduction

This paper reports research on the effects of human capital, infrastructure capital, and foreign direct investment (FDI) on regional inequality and economic growth in China. China's dramatic economic growth since the beginning of economic reform in 1978 has been very uneven across regions. We investigate these related trends for two reasons: (i) to understand their causes, and (ii) to derive implications for policies to harness the causes of growth to reduce inequality in other countries. We model two roles for human capital: (i) educated workers embody human capital that contributes directly to output in the production process itself; (ii) human capital, particularly that represented by higher education, plays an important role in total factor productivity (TFP) growth. Infrastructure capital is hypothesized to affect GDP through TFP growth, as is FDI.

We specify and estimate a provincial aggregate production function in which inputs are specified to include physical capital and two categories of labor: (i) less-educated workers, those who have no junior high school education and (ii) educated workers, those who have some junior high school education or above. The estimated output elasticities of the three inputs are used to calculate factor marginal products and also TFP at existing provincial factor quantities. We then estimate a TFP growth model in which the arguments are human capital operating directly and through regional technology spillovers, infrastructure capital, physical-capital vintage effects, foreign direct investment, and marketization. FDI is treated as an endogenous variable.

We derive three sets of hypothetical policy implications from our empirical results. (1) We use our estimated production function parameters to calculate marginal products of labor and capital and then project how the reallocation of labor to equalize marginal products across regions would affect per capita GDP and the number of workers in each region. (2) We project results of another reallocation scenario—the impact on the time path of regional GDP ratios of a tax-transfer scheme that would increase investment in human capital and/or infrastructure capital. (3) We calculate internal rates of return to policies that would reallocate resources to investment in infrastructure and human capital. We believe the results have important implications for an understanding of economic growth in general, for factors contributing to China's rapidly rising regional inequality, and for the design of policies that would lead to a more equitable distribution of the benefits of growth within the world's most rapidly expanding economy.

The remainder of this paper proceeds as follows. Section 2 provides some background information. In section 3 we lay out our methodology. Section 4 describes our data. Section 5 reports our empirical results for aggregate production functions and TFP-growth models. In section 6, we conduct cost-benefit analysis by computing the rates of return to investment in human capital and telephone infrastructure. In addition, we perform a hypothetical experiment by evaluating alternative investment strategies in reducing regional inequality. Section 7 concludes and provides policy recommendations. The appendixes describe the construction of critical data series and provide details of mathematical derivations.

2. Background

By the year 2000, China found itself with not only one of the highest rates of economic growth but also one of the highest degrees of rural-urban income inequality in the world (Yang, 2002). The rural-urban disparity feeds the wide regional economic inequality (Yang, 2002), which is a relatively new phenomenon in China's last half century. From the beginning of the Mao era through 1986, inequality across major regions (as measured by the coefficient of variation of per-capita real gross domestic product) trended downward, but it rose sharply in the decade of the 1990s (Figure 1).[1] This trend is also apparent from regional per capita GDP shown in Figure 1. The gap between the coastal region and other regions has increased rapidly since 1991. Figure 2 illustrates the rising regional inequality in China since 1978, the start of economic reform, using the ratio of per capita GDP between the three non-coastal regions and the coastal region. The industrial northeast, where per capita gross domestic product

[1] The four regions defined in this study are: coastal (Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, and Guangdong-Hainan); northeast (Heilongjiang, Jilin, Liaoning), interior (Inner Mongolia, Shanxi, Anhui, Jiangxi, Henan, Hubei, Hunan, Guangxi, Sichuan-Chongqing, Guizhou, Yunnan, and Shaanxi) and far west (Gansu, Qinghai, Ningxia, and Xinjiang). We have excluded Xizang (Tibet) province due to lack of data, combined Chongqing with Sichuan and Hainan with Guangdong. The division of the four regions is based on the results of past research and our own judgment regarding the major economic and geographical clusters that characterize distinct "clubs" of economic growth and development in China.

substantially exceeded that in the coastal region at the end of the Mao fell to a position 30 percent less than the coast by 2003. The coast's early advantage over the interior and far west soared to a ratio of approximately 2.4 by 2003. By comparison, among the major regions of the United States in 2004, the ratio of the highest to lowest regional per-capita GDP was only 1.3 (United States Bureau of Economic Analysis, current web site). In China in the year 2003, the ratio of real per-capita GDP between the wealthiest province and the poorest was 8.65, while in India for 2004, the comparable ratio (in nominal terms) was only 4.5 (Purfield, 2006).

2.a *Human Capital and Growth*

China's investment in human capital beyond the level of secondary schooling has been small in comparison with nations at similar levels of per capita income and economic development, and its geographical dispersion has been large (Fleisher, 2005; Heckman, 2005). In 2004, the government expenditures on education were 2.79% of GDP and had been below 3% in most years since 1992, much lower than the average of 5.1% in developed countries. As shown in Table 1, the proportion of the population with some college education (including graduates and postgraduates) was 0.6% in 1982 and had risen to only 1.3% by 1992. Starting in 1999, the Chinese government increased the enrollment of college students sharply. The annual growth rate in college enrollment between 1999 and 2003 was 26.6% (State Statistical Bureau, Various Years).[2] However, by 2003, the proportion of those with at least some college in the national population was still quite low, at 5.2%. The proportion of these individuals in the coastal, far west, and northeast regions was at least 6% in 2003, while in the interior (with nearly 52% of the national population) it was only 4.2%. The proportion of adults who had at least some high school education or more was approximately 20% in the coastal region, 21% in the northeast, but 17% in the far west and 18% in the interior regions.

Although it has long been believed that human capital plays a fundamental role in economic growth, studies based on cross-country data have produced surprisingly mixed results (Barro, 1991, Mankiw et. al. 1992, Benhabib and Spiegel 1994, Islam 1995,

[2] The enrollment data exclude Tibet in order to be consistent with the sample of provinces that we use in this paper.

Krueger 1995, Pritchett 2001, Temple 2001). One reason for this uncertainty is that the impact of education has varied widely across countries because of very different institutions, labor markets and education quality, making it hard to identify an average effect (Temple 1999, Pritchett 2001). Moreover, as Pritchett (2006) points out, major transition economies have been excluded for data reasons from a number of important cross-country studies.

China's dramatic economic growth since the beginning of economic reform, along with wide regional disparities in growth, provides a very important and useful episode for analyzing the effects of human capital on growth. It is widely hypothesized that human capital has a direct role in production through the generation of worker skills and also an indirect role through the facilitation of technology spillovers. In published papers, Chen and Fleisher (1996), Fleisher and Chen (1997) and Démurger (2001) provide evidence that education at the secondary or college level helps to explain differences in provincial growth rates. Liu (2007b, 2007c) demonstrates important external effects of human capital on productivity in rural and urban China. Using a less technical approach than many studies, but one that is highly informative and suggestive, Sonobe et al. (2004) show that subtle and important changes in quality control, efficient production organization and marketing of manufactured goods among emerging private enterprises have been more likely to occur in firms where managers have acquired relatively high levels of education. However, the direct and indirect effect of human capital and especially their impacts on regional inequality in China have not been fully analyzed.

Additionally, a body of research has shown that total factor productivity (TFP) growth has played an important role in post-reform growth in China (Chow 1993, Borensztein and Ostry 1996, Young 2003, Wang and Yao 2003, and Islam et al. 2006), but these papers do not explicitly model the role of human capital in the production function or its role in explaining TFP growth. This study provides a framework and evidence expanding our understanding the role of human capital in production and in TFP growth in China.

2.b **Foreign Direct Investment and Growth**

China's path toward a market economy has been much more gradual than that of most other formerly planned economies, in particular those of the former Soviet Union and Central and Eastern Europe (Fleisher, Sabirianova, and Wang, 2005), but it has not been a smooth path, periods of gradualism alternating with stagnation and sharp jumps. A significant force pushing the economy toward marketization has been the spontaneous growth of local private enterprises, some originating from township and village enterprises (TVEs). Another major force has been the introduction of (partial) foreign ownership through foreign direct investment (FDI).

The role of FDI has received much attention because of its potential for bringing in new production and managerial technologies, with their attendant spillovers (Liu, 2007a). (See Cheung and Lin, 2003 for a thorough analysis and references to earlier literature on FDI in China.). FDI has facilitated the transformation of the state-owned and the collective sectors. The direction of FDI is obviously encouraged by exogenous geographical and political factors such as proximity to major ports, decisions to create special economic zones and free trade areas, local institutional characteristics such as laws and regulations, contract enforcement, and so on,, local expenditures on infrastructure, schools, etc, and by labor-market conditions. Moreover, there is likely to be a degree of endogeneity in these relationships between FDI and TFP growth if TFP growth encourages FDI (Li and Liu, 2005). One of the major features of our research is to incorporate the endogeneity of FDI in a model explaining China's increased regional economic disparity.

2.c *Infrastructure and Growth*

Still another major source of growth has been investment in infrastructure capital. At the beginning of reform, transportation and communications infrastructure were poor, but governments at various levels have invested heavily in the construction of highways, expansion of rail systems, and development of electronic communications facilities. Research that neglects the marketization process, opening to the outside world, and investment in infrastructure capital would yield incomplete, and probably biased, understanding of the role of human capital to the extent that local human capital stock is correlated with those factors.[3]

2.d *Marketization, the Profit Motive, and Hardened Budget Constraints.*

In addition to physical infrastructure discussed above, institutional infrastructure such as marketization can also be an important factor supporting economic growth. As China's market oriented reforms deepening, the market mechanism plays an increasing role in the country's economy. An important aspect of China's transformation is its uneven pace. It is generally agreed that a sharp acceleration in China's gradual "growth out of the plan" (Naughton, 1995) followed Deng Xiaoping's famous spring, 1992 "South Trip" in which he reaffirmed his belief in policies that not only allowed, but encouraged, Chinese citizens to follow the profit motive in the quest of personal wealth. This trip was very important, because it thwarted the conservative force that tried to stop market oriented reform following the Tiananmen Sqaure events of 1989. By doing so, it speeded the pace of transition to a market system.

Although urban economic reform began in the period 1983-85, the Chinese economy was still largely operating under the old planning system before 1992, with the share of state-owned enterprises (SOEs) accounting for more than half of gross industrial output. After Deng's visit to south China, the country moved much more quickly towards an open, market economy. In the period 1992 to 1994, the share of SOEs in industrial output dropped 14 percentage points (from 48.1% to 34.1%), an annual rate over three times as rapid as during the period 1978 to 1992. The SOE share in industrial output fell to 13% by 2003.

The year 1994 marked the beginning of withdrawal of government subsidies for loss-incurring SOE's, and this hardening of budget constraints became much more earnest in 1997 (Appleton et al., 2002). There was also a shift toward fiscal federalism after 1994 that, through separating central and local government taxation and relaxing ties between provincial and sub-provincial treasuries and the center, reinforced imposition of hard budget constraints on SOEs (Ma and Norregaard, 1998; Su and Zhao,

[3] Fleisher and Chen (1997) and Démurger (2001), among others, provide evidence of the importance of infrastructure investment for productivity and economic growth in China.

2004; Qian and Weingast, 1997). Fiscal reform made local governments responsible for subsidizing sub-provincial-owned state enterprises, thus providing strong incentives for the local governments to shift their expenditures to projects that would attract FDI, particularly infrastructure projects (Cao, Qian, and Weingast, 1999). Despite the potential contribution of these reforms to improved economic conditions, implementation was by no means perfect (Ma and Norregaard, 1998). Therefore, we account for the intensification in the impact of market reforms after 1994 in the specification of our empirical models.

3. Methodology

We estimate provincial aggregate production functions in which inputs are specified to include physical capital and two categories of labor: (i) less-educated workers, those who have no junior high school education and (ii) educated workers, those who have some junior high school education or above. The estimated output elasticities of the three inputs are used to calculate factor marginal products and also TFP at existing quantities of the inputs . This strategy permits us to investigate two possible channels through which human capital may influence output. One channel is a direct effect, in that educated workers should have a higher marginal product than less-educated workers. The second channel is indirect, through TFP growth. We hypothesize that provinces with a relatively large proportion of highly educated workers benefit from being able to develop and use new production techniques as well as from absorbing technology spillovers from the provinces with higher technology levels.

The incorporation of a measure of human capital "inside" the production function is based on micro-level evidence that workers with more education are more productive. For example, in analysis of firm data for China, Fleisher and Wang (2001, 2004) and Fleisher, Hu, and Li (2006) find evidence that highly educated workers have significantly higher marginal products than workers with lower levels of schooling. Our inclusion of human capital measures inside the production function is not unique. For example, Mankiw et al. (1992) have done so using aggregate data. Other researchers, such as Nelson and Phelps (1966), Islam (1995), and Benhabib and Spiegel (1994), however, suggest that human capital mainly operates through total factor productivity (TFP), because it facilitates the development and adaptation of new technology. We adopt a mixture of these approaches to estimating the impact of investment in human capital on output and growth.

Another issue that must be addressed in specifying the aggregate production function is the intensification of the exposure of Chinese firms, in particular SOEs, to market competition, and government decisions to accelerate the hardening of budget constraints for SOEs since 1997 (Appleton, et al, 2002). It seems likely that not only did SOEs increase their productivity in response to market competition reinforced by administrative tightening of their ability to borrow funds to offset losses, but also that some SOEs, at least, proved to be more formidable competitors for firms in the private and quasi-private sectors. Striking (although somewhat casual) evidence of the impact of the acceleration of market reforms is illustrated in Figure 3. The real GDP series and capital stock series are in sharp contrast to the labor series. While GDP and capital stock increase at steady annual rates of about 10% and 9% per year, respectively, throughout the period 1985-2003, employment *declines* abruptly between 1997 and 1998 and grows very slowly through 2003. Detailed analysis of individual provinces reveals considerable variation in employment and output growth, with employment in Shanghai, for example lower in 2003 than in 1993 although GDP more than tripled over the same period; in contrast in western and much poorer Shanxi, employment also declined in the late 1990s, but by 2003 was somewhat higher than in 1996.

Clearly, a direct impact of tightening budget constraints was on redundant workers in SOEs. SOEs employed more production workers than would have been implied by cost minimization or profit maximization (e.g, see Fleisher and Wang, 2001), the so-called hidden unemployment problem. When SOEs were restructured, a large number of workers were laid off, especially after 1997. These laid-off workers are designated as *xiagang* workers, which is a different category than *unemployed,* because they are still attached to their original employers and receive some benefits. Data on the number of *xiagang* workers are reported by enterprises starting in the year 1997- consistent with the hypothesis that the serious impact of hardened budget constraints began to be felt only after 1997 (Appleton et al., 2002). The *xiagang* series is shown in Figure 4. As Figure 4 illustrates, the reported number of *xiagang* workers (at the national level) peaked in 1997. The sharp and steady decline after 1999 occurred because laid-off workers may retire, become re-employed by their former enterprises or by other enterprises, or, after three years, they may simply be dropped from the *xiagang* roles.

The impact of SOE restructuring is reflected in the number of workers, especially less-educated workers employed in production, with fewer workers producing more output. Clearly, such a negative correlation between an input and output may lead to a negative estimated output elasticity. This change in the structure of production was by no means equal across provinces and years, and thus fixed effects cannot control for it.[4] Therefore, we have a particular omitted variable problem in estimating the aggregate production function. A variable reflecting SOE employment efficiency is not included in the basic production-function specification, and it is correlated with the aggregate employment level, especially that of the less-educated group.

In order to account for this problem, we have incorporated alternative proxies for the productivity change in specification of the aggregate production function. The most general approach would be to specify provincial specific effects for each year. However, we do not have sufficient degrees of freedom to implement this approach. A less general alternative would be to allow each of the four regions to have regional-specific annual effects by interacting regional dummies with annual dummies in the estimation. A similar but different approach would be to allow for province specific effects which vary before and after the start of SOE restructuring, i.e., to interact each province dummy with a year dummy that marks breaks in employment efficiency.

The two approaches described above are more or less standard procedures in panel data estimation, but they are rather mechanical. In order to find a less mechanical proxy for the change in employment efficiency, we have searched for more flexible ways to represent the hardened-budget-constraint and competitive-markets impacts. One method is to define an employment efficiency variable as

$$E_{it}^{a} = e^{a_i \cdot Trend + b_i \cdot Trend^2}$$

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[4] As can be seen in the empirical result section, the estimated output elasticity for less-educated workers is negative in simple two-way fixed effects estimation. The result is not surprising given that less-educated workers were those most heavily affected by the SOE restructuring.

Where *Trend*=0 before 1997, and for t ≥1997, *Trend*= t – 1996 ; a_i and b_i are provincial-specific coefficients. The provincial specific quadratic trend variable is designed to capture the effect of improvement in employment efficiency in the SOE sector that began in 1997; the quadratic feature allows for province-specific decelerating or accelerating adjustment paths.

An alternative measure of the improvement in employment efficiency is to incorporate the *xiagang* series directly in the production. We define this proxy r employment efficiency proxy as

$$E^b_{it} = [\max(1 + xiagang_{it} / SOE_{it}, E_{i,t-1})]^{a_i} \text{, for t=1986, 87, … , 2003.}$$

There were no reported *xiagang* workers in 1985, so $E_{i,1985}$=1. The variable SOE_t is total SOE employment in year t and $xiagang_t$ is the total number of *xiagang* workers reported in year t. The parameter a_i allows the *xiagang* effect to be specific for each province. The efficiency proxy is assumed to be monotonic with a durable increase in employment efficiency. Thus we use the largest value of the ratio in any year up to the current year (t) as a measure of improved efficiency as of the year (t).

Therefore, the production function including two types of labor and a proxy for employment efficiency is defined as:[5]

$$Y_{it} = A \cdot K^{\alpha}_{it} \cdot (E_{it} \cdot L^{\beta}_{eit} L^{\gamma}_{nit}) \cdot e^{u_{it}} \qquad (1)$$

where *Y* is output, *K* is capital, L_e is the number of educated workers, those with more than elementary school education, L_n is the number of less-educated workers, those who have less than junior high school education, *E* is one of the proxies for the improvement in employment efficiency as defined above, and *u* is a disturbance term, for province i= 1, 2, …, n from year t=1, 2, …, T.[6] The parameters α, β, and γ are the output elasticities of the corresponding inputs.

[5] Jones (2005) shows that the Cobb-Douglas form is a valid approximation in the aggregate for a variety of underlying micro firm production functions.

[6]. In the production function, the group of workers with more schooling includes those who have gone beyond elementary school . In the TFP-growth equation the group of workers with more schooling includes only those who have at least matriculated in senior high school. Our rationale for this distinction is that TFP growth is a function, in part, of technology spillovers, and we postulate that at least some senior high school education is necessary to be effective in absorbing technology spillovers. It can be argued that the higher schooling group should be limited to workers with college diplomas, but the proportion of these workers in the earlier years of our sample was extremely small. There is evidence that in the earlier stages of the growth of private enterprises in China, important advances in marketing strategies, quality control,

The above production equation is estimated in a two-way fixed effects model. Moreover, we will also apply the Common Correlated Effects Pooled (CCEP) estimator developed by Pesaran (2006) to take into account cross province dependence in our data; and we use a standard error estimator that is robust to serial correlation, heterosckedasticity, and cross-sectional correlation in panel data (Driscoll and Kraay 1998).

In addition to its direct effect on output, human capital is believed to facilitate development and adoption of new technology, which is reflected in TFP. Thus, we investigate those effects of education in a TFP growth model along with other factors generally hypothesized to affect TFP, including FDI and local infrastructure capital. We first address the role of human capital. Following Nelson and Phelps (1966), we postulate that the diffusion of technology is positively related to human capital. Nelson and Phelps specify the growth rate of technology as

$$\frac{T\dot{F}P_t}{TFP_t} = \Phi(h)\left[\frac{TFP_t^* - TFP_t}{TFP_t}\right], \tag{2}$$

$$\Phi(0) = 0, \qquad \Phi'(h) > 0$$

so that the growth rate of TFP is dependent on human capital (*h*) and the gap between its actual level and a hypothetical maximum level of TFP (TFP_t^*). The expression $\frac{TFP_t^* - TFP_t}{TFP_t}$ represents the technology gap, and $\Phi(h)$ represents the ability to adopt and adapt the technology, which is an increasing function of human capital (*h*). Thus, the new technology developed by an advanced region can have spillover effects to the benefit of poorer regions. Equation (2) describes the process of technological diffusion in what might be characterized as a learning-by-watching process.

Benhabib and Spiegel (1994) extend Nelson and Phelps' (1966) framework to include domestic innovation. They specify TFP growth as a function of human capital, and human capital is modeled to have both a direct effect (innovation) and an indirect spillover effect working through technological diffusion. The indirect effect is captured by the interaction of human capital and the output gap:

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and enterprise organization occurred in firms whose management had more than elementary, but less than college education (Sonobe, et al, 2004).

$$[\log TFP_{iT}(h_{it}) - \log TFP_0(h_{it})] = c + gh_i + mh_i[\frac{Y_{max} - Y_i}{Y_i}] \tag{3}$$

where Y_{max} is the highest level of provincial output in the regions studied (e.g., provinces in China), TFP_0 is total factor productivity in the initial year, c denotes the exogenous progress of technology, gh_i represents domestic innovation, and $mh_i[(Y_{max} - Y_i)/Y_i]$ denotes technology diffusion.

Our full model represents provincial TFP growth as a function of human capital, infrastructure capital, physical-capital vintage effects, foreign direct investment, marketization, and regional technology spillovers as follows:

$$\begin{aligned} TFPgrowth_{i,t} &= \eta_{1,i} + \eta_{2,t} + \varphi_1 FDI_{i,t-2} + \varphi_2 FDI\_YB_{i,t-2} \\ &+ \phi_1^h h_{i,t-1} + \phi_1^s hs_{i,t-2} + \phi_2^s hs\_YB_{i,t-2} + \delta_1^m Mkt_{i,t-1} \\ &+ \delta_1^v \Delta_t^2 K_i + \beta_1^r Road_{i,t-1} + \beta_1^t Tel_{i,t-1} + \mu_{i,t} \end{aligned} \tag{4}$$

To capture the impact of a break in the reform process following Deng Xiaoping's "South Trip," we impose a structural break in 1994. *YB* is a break dummy which is set to be 1 if before 1994. The journey took place in the last weeks of 1992, and a one-year lag in its impact seems reasonable. The policy impact of the trip was to open the country to profit-seeking domestic activity, which up to this time had been most strongly encouraged through foreign investment in special economic zones. Thus we should expect a break in the special impact of foreign investment and increase in the likelihood that domestic enterprises would benefit from technology spillovers. We also include a proxy of the degree of marketization *Mkt*, in the local economy, and it is measured by the proportion of urban labor employed in non-state owned firms. This group of firms includes share holding units, joint ownership units, limited liability corporations, share-holding corporations, and units funded from abroad, Hong Kong, Macao and Taiwan. Marketization and competition should lead to higher efficiency, thus increasing TFP growth due to the efficiency and competition effects across firms.

Tel is a proxy of telecommunication infrastructure, defined as the percentage of urban telephone subscribers in the population. *Road* is a proxy for transportation infrastructure, defined as the length of road per squared kilometers. Given the possible delay in their effect on TFP growth, most variables in the model are lagged.[7] The dummy variables $\eta_{1,i}$ and $\eta_{2,t}$ represent provincial and annual fixed effects, respectively.

Following Wolff (1991) and Nelson (1964) we include the second difference in physical capital, ($\Delta_t^2 K_i$) to reflect the assumption that new capital embodies the most recent technology. We use its current value to capture the current effect of the quality of physical capital on TFP growth and to save degree of freedom (i.e., save one year of data).

We measure human capital h_i in the TFP-growth equation as the percentage of the population with either (i) some college or above) or (ii) some senior high school or above. The impact of schooling on TFP is posited to come from the ability to invent and/or adapt new technology, which requires a higher level of sophistication than elementary school education. Thus, the education level categories in the TFP regression break at a higher schooling level than do the categories in the production function. However, because the proportion of college-educated workers in China was extremely small throughout our sample period, the impact of this education group on TFP growth is likely to be difficult to detect in our data. Therefore, we use two measures of the schooling break to see which one appears to have more impact on TFP growth.

We assume that the technology spillover process associated with human capital is limited by frictions and costs positively associated with distance. A region that is closer to the most advanced region is assumed to have better access to new technology than more distant regions. To capture this effect, the output gap is discounted by the railway distance between the capital city of each province and the capital city in the province with the highest output per capita (which is typically Shanghai). This distance variable is specified as $d_{\max\_i}$, and the variable y_i denotes output per capita. Thus, we define the human-capital spillover variable as: $hs_{it} = h_{it} \cdot [\frac{1}{d_{\max\_i}}(\frac{y_{\max,t} - y_{it}}{y_{it}})]$. We impose a two-period lag for the human capital spillover effect, because we assume that it operates with a longer lag than does the direct effect. This specification also helps us to avoid a simultaneity arising from the construction of the spillover variable. Since the extent of

[7] The results are not sensitive when we lag the variables one more period in the model.

spillover is more likely to be affected by economic structure correlated with the uneven time path of reforms discussed above, we interact the spillover variable with the break dummy, *YB*, to reflect this possibility.

We are looking for *causal* relationships between human capital and both production and TFP growth. Therefore we must be concerned with the possibility that the proportion of educated persons in a province's population is the result of high income or high return to schooling. Bils and Klenow (2000) argue that the cross-country correlation between schooling levels and TFP growth could be partly due to omitted variables positively related to both variables, such as property-rights enforcement and openness as well as an endogenous response of schooling choices to the expected return to investment in human capital. Our use of data across provinces within a single country reduces the impact of legal-institutional differences, such as property rights definition and enforcement on TFP growth. The provinces vary immensely in both the amounts spent on education per capita and in the proportion of provincial GDP spent on education. Over the period 1999-2003, the maximum-minimum ratio of per-pupil expenditure across provinces exceeded a factor of 10, while the ratio for proportion of GDP spent on education exceeded 3.5 (Heckman, 2005). We control for the possible bias caused by omitted variables by using two-way fixed effect estimation.

Another problem in obtaining unbiased estimates of the impact of human capital on output and growth would be "brain drain" of persons with higher levels of schooling from the places where they obtained their schooling to locations where their productivity is higher and growing faster. This possible source of bias, while present, is attenuated in China by interregional and interprovincial migration restrictions due to residency-permit, or *hukou* requirements, even though *hukou* barriers to migration are lower for college graduates (Liu, 2005). Universities are located in large urban areas and provincial capitals, and their locations have been determined by historical factors, and political considerations, defense goals, and the like. Thus it is reasonable to assume that universities tend to generate exogenous impacts on growth rather than that their locations have been the result of growth. Additionally, given that our education breaks are above junior high school or above elementary school, endogeneity bias is likely to be less than if our schooling break were for college and above, because the *hukou* restriction and other non-market barriers are much more common for less educated workers in the Chinese labor market. Moreover, as Zhao (1999) shows, rural citizens tend to prefer off-farm work in rural locations and small towns to migration to distant urban locations. For rural to urban migration, Li and Zahniser (2002) find that the most educated members in rural society are less likely to migrate.[8]

We include a variable representing foreign direct investment, FDI_{it}, the ratio of real foreign direct investment to the total work force, which is assumed to represent the embodiment of foreign technology. Since the impact of FDI is likely to be determined by the advance of marketization, we add an interaction term between FDI and the break dummy, *FDI_YB*, to control for it. Given the probable lag between investment and placing new capital into production, we lag FDI two years relative to the TFP growth series. Because previous FDI presumably is not affected by the current TFP growth, this specification also mitigates an endogeneity problem that could result from the possibility that locations with higher TFP growth may offer higher investment returns and thus attract more FDI. However, if investors are forward looking, foreign investment may be correlated with future shocks in TFP, it is still possible to have correlation between lagged *FDI* and the contemporaneous errors in the model.

To address this problem of possible endogeneity of FDI, we apply IV estimation. In panel data estimation, it is notoriously difficult to find good instruments for FDI because important exogenous variables that affect FDI are geographical, and thus fixed and perfectly collinear with fixed effects. Clear examples are location relative to preexisting transport hubs (canals, major rivers) and port availability.[9] In the search for a good instrument, we turn to government policies for attracting FDI. Since the start of economic reform, Chinese central government and local governments have set a variety of preferential policies to attract FDI, such as policies on taxation and the use of land. A well-known example of such a policy is to establish special economic zones (SZs).

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[8] We thank Alan de Brauw for sending us a specially compiled table from the 2000 Population Census of China which contains data on the fraction of 1995 college graduates of each province who lived in another province in 2000 and the fraction of college graduates in each province in 2000 who lived in another province in 1995. When the latter fraction is subtracted from the former, the result is negative for all coastal provinces except Guangxi. This is inconsistent with the hypothesis that there was net migration of college graduates to the coastal provinces.

[9] Hale and Long (2007) used port availability and access to domestic market of the province as an instrument for FDI.

Shenzhen is a well known special economic zone. Although some SZs have been established in coastal locations, others were established for political or technical reasons; they boast features and names such as “duty-free” zones, “high-tech zones” “opening zones” and so on. SZs offer a variety of preferential tax rates that are less than the standard 33%, according to their sub-category designations. For example, for firms in a designated Special Economic Zone the tax rate is 10-15%; for those in “opening” and “coastal” cities, tax rates are in the range 12-30%; firms in “duty-free” and “high-tech zones” pay tax at a rate of 10-30% with the possibility of a zero tax rate for the first three years and half of the preferential rate for the following three years.[10] Given the political and technical considerations for establishing a SZ by the central government and the time needed to establish and implement these policies, it is reasonable to assume that they affect FDI but are exogenous to the current TFP growth. Therefore, we view SZ policy variables as appropriate instruments for FDI.

To construct FDI instruments, we divide the different type of SZs into three categories, i) National Special Economic Zone such as Shenzhen (the total number of such cities in a province represented by the variable *Zone3*);[11] ii) Duty-free, or High-tech, or Economic Development cities or zones (the total number of such cities or zones in a province represented by the variable *Zone 2*);[12] iii) Opening City, such as Guangzhou (*Zone 1*). For each province, we create the three instruments defined above. These instruments capture preferential tax policies. The degree of tax preference increases from *Zone1* to *Zone3*. We hypothesize that the larger the value of the instrument, i.e., the more cities with preferential tax policy in a province, the more likely is it that the province will attract FDI. There are sufficient changes in the *zone* variables over space and time to permit reasonable variation in these variables on both dimensions.

4. Data

[10] The tax rates can be found in “Income Tax Act for Foreign Invested Firms and Foreign Firms in People’s Republic of China.”

[11] There are six National Special Economic Zones so far. They are: Shenzhen, Zhuhai, Shantou, Xiamen, Hainan, and Shanghai Pudong.

[12] Such a zone can be a city, like Hefei in Anhui province; or it can be an area within a city, like Zhong-Guan-Cun in Beijing.

Our data are from various years of the China Statistical Yearbook, Population Census (1983, 1993, and 2001), Annual Population Change Survey (State Statistical Bureau, 1993, 1996-2000, 2002 and 2003), Hsueh, Li, and Liu (1993), Sylvie Démurger (personal communication), Fu (2004), and China Data Online (2008). One important feature of this study is that our data are not only deflated over time but also by an index that accounts for living-cost differences across provinces. Therefore, our data are comparable across provinces where living costs are quite different. GDP and capital-stock deflators are based on official price indexes (China Statistical Yearbook) linked to the 1990 national values of a typical living expenditure basket reported in Brandt and Holz (2006), specifying Beijing as the base province and 1990 as the base year.[13]

To estimate the capital stock for each province, we adopt Holz's (2006) cumulative investment approach. Holz's method adjusts official data so that investment- and capital-stock figures more closely approximate appropriate theoretical concepts of productive capital. The equation for constructing capital stock follows Equation 7' in Holz (2006):[14]

$$ROFA_t = ROFA_0 + \sum_{i=1}^{t} \frac{investment_i}{P_i} - \frac{scrap\_rate_i * OFA_{i-1}}{P_{i-k}}, \quad k = 16,$$

where $ROFA_t$ is "the real original value of fixed assets", and k is "the average number of years between purchase and decommissioning of fixed assets" (Holz, 2006).[15] The variable $investment_i$ is effective investment, defined as the product of the transfer rate and gross fixed capital formation. Holz defines the transfer rate as the ratio of official effective investment to official total investment expenditures.[16] The variable $scrap\_rate_i$

[13] The capital-stock deflator is constructed as follows. The first step is to construct the implicit deflator of gross fixed capital formation for the period 1966-1990. The second step is to combine the implicit deflator series with the official price indices of investment in fixed assets (available since 1991 from China Statistical Yearbook). The third step is to construct the comparable provincial capital-stock deflator, assuming 50% of components in the original deflator series are comparable across provinces and the remaining provincial differences in the deflator series can be accounted by Brandt and Holz's (2006) 1990 national values of a typical living expenditure basket.

[14] An alternative approach to construct physical capital is the NIA method also discussed in Holz (2006). Fleisher, Li and Zhao (2006) use the NIA approach. In this study, we apply the cumulative investment approach, because based on Holz (2006), this approach works better in panel data and in controlling for the problem caused by the official revaluations of the original values of fixed assets in 1993.

[15] Holz (2006) suggests that $k = 16$ or above is preferred.

[16] Due to the lack of data, we use Holz's (2006) the estimated national transfer rates to approximate provincial transfer rates.

is set to be 1% in the initial year, and it is moved linearly up to 2.5% in 2003.[17] The variable P_i denotes the price index for investment. Due to the lack of investment price data prior to 1991, we construct an implicit deflator for capital formation for the years 1966 through 1990 from State Statistical Bureau (1997).[18] The initial value of fixed assets (OFA_0) is assumed to be the nominal depreciation value over the depreciation rate, which is set at 0.05. For a discussion of assumed depreciation rates see Wang and Yao (2003).

The numbers of people with some college education or above and with some senior high school education or above are estimated based on the annual flow of college student enrollments and senior high school student enrollments, respectively, anchored to periodic population census data and annual population change survey data. The census data (1982, 1990, and 2000) and the annual population change survey data (1993, 1996-1999, 2002, and 2003) provide the proportions of people by educational levels.

The infrastructural data are provided by Sylvie Demurger for the years 1978 through 1998 and from State Statistical Bureau for the years 1999 through 2003. Data on employed workers by education levels are obtained from the annual population change surveys (provided in China Statistical Yearbook) for the years 1996 through 2003; prior to 1996, they are estimated by assuming the educational composition of the workforce is the same as that of the total population. Foreign direct investment data from 1985 to 1996 are obtained from China Statistics Press (1999). Data after 1995 are from State Statistical Bureau (various years). The original data (in U.S. dollars) are deflated using the U.S. GDP deflator with 1990 as the base year. Summary statistics are reported in tables 2a, 2b and 2c.

As can be seen in tables 2a, 2b and 2c, the ratio of workers with some junior high school education or above to those with less education averaged about 0.66 in 1985, rose to 0.95 in 1994 and reached 1.81 in 2003. The average ratio of individuals with at least a senior high school education in the population was about 9.6% in 1985, rose to 11.2% in 1994, and reached 19.7% in 2003. There is considerable variation in this ratio across

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[17] This imputation was kindly suggested by Carsten Holz.

[18] We first collect nominal values and real growth rates of gross fixed capital formation. Then, we construct the implicit deflator as follows: [(nominal value)$_t$ / (nominal value)$_{t-1}$] / (real growth rate)$_t$ = [(Price$_t$ × Quantity$_t$) / (Price$_{t-1}$ × Quantity$_{t-1}$)] / (Quantity$_t$ / Quantity$_{t-1}$) = Price$_t$ / Price$_{t-1}$.

provinces. The distribution of FDI per worker also varies widely across provinces and has increased sharply over time. Between 1985 and 1994, FDI jumped from $5.01 (US)/worker to $60.56/worker; subsequently, the rate of increase was slower, reaching $75.35/worker in 2003. The acceleration of capital formation is distributed very unequally across provinces, and it exhibits a downward trend.

Telephone infrastructure intensity increased dramatically and accelerated over the entire period, while road intensity increased, but more slowly, also accelerating in the second decade. Market-economy development as measured by the ratio of the number of workers employed in urban non-state sectors to total urban employment increased 13-fold between 1985 and 1994 and 2.9 times between 1994 and 2003. However, the ratio is still quite low in absolute terms and in comparison to other transition economies (Fleisher, Sabirianova, and Wang, 2005), less than 6% in 2003, and the variation across provinces is extremely high.

Data for preferential tax policies are taken from the government official website for investment guidelines, http://www.fdi.gov.cn. For each province, we added those cities to get the number of cities in each SZ category in that province for that year. As can be seen in table 2a-2c, the average number of special zones in each category increases over time, especially from 1985 to 1994. In this period, the national average number of Opening Cities increased from 0.46 to 1.21 in each province; while the number of Duty-Free, High-Tech, and Economic Development City/Zone increased from 0.43 to 2.14. The increase, however, decelerated from 1994 onward as the government diminished the pace of granting special zone status.[19] One reason for that policy change was increasing pressure to stop preferential tax policy for foreign invested firms so that domestic and foreign firms would compete on a level field.[20]

[19] From 1994 to 2003, the average of *Zone1* declined for some regions and at the national level. The reason is that some cities were left to a higher level, i.e., from *Zone1* to *Zone2*, in later years.

[20] In 2008, the Chinese government started to implement a new law to unify tax rate for both domestic and foreign firms, and removed preferential tax policies for FDI. The unified profit tax rate is 25%, http://www.mof.gov.cn/news/20070322_3258_25832.htm.

5. Empirical Results

Table 3 reports estimation results for a provincial-level production function with two types of labor categorized according to educational attainment. All standard error estimates are robust to corrections for serial correlation, heteroskedasticity, and cross-sectional correlation based on Driscoll and Kraay (1998).

Column (1) reports the standard 2-way fixed effects (FE) estimate. In this specification, the estimated elasticity of less-educated worker is negative and marginally significant.[21] The negative elasticity for less-educated workers is very robust to different production-function specifications and estimation methods. For example, it remains negative under alternative production function forms, such as translog and CES. In order to test whether the estimated negative elasticity is caused by cross-provincial correlation, we apply the newly developed Common Correlated Effects Pooled estimator (CCEP) Pesaran (2006), which is consistent in the presence of cross section dependence in panel data. The CCEP estimate for the elasticity of less-educated workers is also negative.[22] The specification in column (2) adds regional-specific annual time dummies to reflect regional-specific annual changes in employment efficiency; the specification in column (3) is based on 2-way FE plus province-specific year-break dummies (=1 after 1996 and 0 for1996 and earlier). The estimated output elasticity of less-educated labor based on these commonly used treatments is positive.[23] The specifications reported in columns (4) and (5), include a more direct proxy for improvement in SOE employment efficiency.

In columns (2) through (5), all of which include variables to control for the 1997 productivity shock, the sum of the estimated output elasticities ranges from approximately 0.55 in column (2) to slightly over 1.0 in column (5). It is plausible to assume constant returns to scale in the aggregate production function, and the robustness of our returns-to-scale estimates based on the more flexible specifications in columns (4) and (5) is reassuring. In column (2), the estimated capital elasticity is about 56% that of

[21] It is negative and significant if the standard error estimate is not adjusted for error structure or is adjusted only for heteroskedasiticity.

[22] The CCEP estimate of elasticity for capital is 0.38, for educated labor is 0.28, and for less educated labor is -0.11.

[23] In column (2) with region-specific time varying effects, the estimated elasticity for less-educated workers is positive but insignificant. We believe that this result is due to there being small number of regions, with all provinces in one region restricted to have the same annual effect.

more-educated labor, whereas in the three other specifications, it is greater than the elasticity of the more-educated labor. In columns (2) through (5), the ratio of the elasticity of labor with higher education to that of labor with elementary-school education or less is about 8 in column (2) and about 4 in columns (3) through (5).

We also estimated the specification of column (4) using the CCEP estimator, and the results are very close to each other.[24] The CCEP estimates for the elasticity of capital, educated labor and less-educated labor are 0.48, 0.39, and 0.10, respectively.[25] The three regressions specified to reflect province-specific adjustments to the 1997 productivity shock yield quite similar estimates of the inputs' elasticities. This robustness is important not only because it increases our confidence in the estimated parameters themselves, but also because the relationship among the elasticities, in particular the elasticities of the two labor categories, are used to derive important policy implications. In the discussion of sections 5.1 and 5.2, we use the production function estimate from column (4) with quadratic trends. We believe that this treatment is more general than the others; the following discussions and use of these results are robust to the alternative specifications of the production function that control for structural change in employment.[26]

5.1 Provincial marginal products

One way to view regional productivity disparities is to use the estimated production function to calculate provincial marginal products of labor (MPL) and capital (MPK) at existing factor quantities. Between 1984 and 2003, MPL of educated labor calculated at existing factor quantities increased over fourfold and that of workers with elementary schooling or less increased more than 10-fold in the coastal region. However, these rates of increase were not achieved in the other three regions. The ratios of MPL in

[24] In this case, we use a quadratic trend in the observed common effects for the CCEP estimation. Based on Pesran et al. (2006), we rescale the trend by t/T.

[25] The basic idea of CCEP is to filter individual-specific regressors by cross-section averaging and thus the differential effects of unobserved common factors are eliminated. For the specification of column (5), however, the cross-section averages of the efficiency proxy used in the production function do not change for a number of years due to its construction, and thus they become perfectly collinear in the CCEP estimation. Therefore, we do not estimate this specification with CCEP.

[26] We use the 2-way FE estimates instead of CCEP estimates to calculate marginal products and TFP in the following analysis, because the CCEP estimator depends on there being a large number of cross-section units so that the differential effects of unobserved common factors can be eliminated by cross-section averaging. There are only 28 provinces in our sample, and we take this to be quite a small number. On the other hand, the results from both estimators are close to each other.

each of the three other regions to that of the coast for the two classes of labor are shown in figure 5. For workers in the lower schooling group, the regional ratios of MPL in the both interior and far west to the that in the coast declined from about 0.6 to less than 0.4, reflecting substantial productivity divergence. Although the ratio for the northeast region also declined, it reflected productivity convergence, from a 60 percent advantage in 1985 to approximate parity in 2003. Ratios for workers in the higher-schooling group reflect productivity divergence for all three regions, especially through about 1995. Since then, MPL of this group in the northeast region has recovered relative to the coast, but remained at only 80 percent of that in the coast in 2003, compared to approximate parity in 1985. [27]

MPK, which is an approximation of the rate of return to physical capital at existing factor quantities, started out high and has remained high (reaching over 0.3 in all regions except the far west in 2003). Moreover, has converged among all regions except for the far west, which fell behind the other regions after 1996. The high level of MPK is noteworthy in the presence of economy-wide growth in ratios of physical capital to labor. An interesting question would be to ask what would happen if labor were reallocated among provinces to equalize marginal products. For example, for workers with schooling no greater than elementary level, the reallocation (holding physical capital and the other labor category constant) would raise per capita GDP in the interior and far west by about 7% and 5% respectively, while reducing their workforces in these regions by almost half. On the other hand, per capita GDP would fall in the coast and northeast while their workforces would absorb all the relocated labor from the other two regions. The social and political implication of such drastic policies would be immense, not to mention the attendant costs of schools, hospitals, houses, etc. Reallocation of more-educated workers would also result in massive population redistribution, but would increase regional income disparities. We believe that policies to promote growth are likely to have higher payoff and to be met with greater acceptance by Chinese citizens.

[27] It should be emphasized that the hypothetical relocation experiment involves only geographical reallocation of workers without specifying anything about possible misallocation among firms. In a recent NBER working paper, Hsieh and Klenow (2007) use micro data for China and India to estimate the impact of misallocation of labor and capital across plants within narrowly defined industries. They find that manufacturing TFP is substantially reduced as a result of interplant resource misallocation in both countries—by 25-40% in China and substantially more in India.

5.2 Total Factor Productivity Growth

TFP growth has important implications for regional disparity in China's economic development. In the interior region, TFP was over 80% that of the coastal region in 1985, and it has fallen rather steadily to less than 70% that of the coastal region by 2003. A similar picture holds for the far western region compared to the coastal region and for both the interior and far west relative to the northeast. Clearly, targeting regional TFP growth should be an important aim of economic policy in China.

In order to understand the determinants of TFP growth, as discussed in the methodology section we model TFP growth as a function of FDI, physical capital vintage, the degree of marketization, and human capital, with human capital operating through two channels, both a direct effect on TFP growth and an indirect effect through technology spillovers.[28] TFP growth regression results are presented in tables 4 and 5.[29] In Table 5, variables representing infrastructure capital are added as regressors, and we report the results based on dynamic specifications. Table 4 reports the base results of three specifications, two of them using 2SLS because of the possible endogeneity of FDI.[30] The regressions are based on the production function reported in Table 3, column (4), which include the quadratic time trend variable in E_{it}^{a}.[31]

Columns (1) and (3) in Table 4 permit us to see the impact of using 2SLS to address the problem of FDI endogeneity. A Hausman test on the endogeneity of FDI rejects the null that FDI is exogenous. The first stage result confirms that most of the instruments are significant, and the overidentification test (Hansen J-statistic) does not reject the null hypothesis. This result is comforting as it shows no evidence against our instruments. Columns (2) and (3) in Table 4 allow us to compare the results of two

[28] While there is little doubt that the shift of workers from low-productivity agricultural work to higher productivity work elsewhere has been a major force in China's economic growth (Young, 2003), we do not explicitly model geographical and intersectoral migration in this paper.

[29] Since our TFP model is based on FE+IV estimation, we do not use the CCEP estimator, because it has not been shown that it is applicable.

[30] In tables 4 and 5, the standard error estimates for 2-way FE are robust to corrections for heteroskedasticity, serial correlation, and cross-sectional dependence based on Driscoll and Kraay (1998). For the IV plus 2-way FE procedure, we use the Stata standard package xtivreg to conduct the estimation. As an additional check, we compare the standard errors produced by xtivreg with the ones produced by xtivreg2 with robust option (Schaffer, 2007), and they are similar to each other..

[31] In all regressions, the F-test on fixed effects strongly rejects the null of no fixed effects.

different definitions of schooling categories, above senior high school and above junior high school. The two most notable differences between the FE-only regression and the regression result based on FE plus 2SLS are (i) the estimated impact of FDI in years prior to 1994 is almost six times larger under 2SLS and the human capital spillover impact in years prior to 1994 is about 2.5 times larger. The other estimated coefficients in the 2SLS regressions tend, if anything, to be somewhat larger and generally no less significant than those estimated by FE. The regression results are reasonably robust to specification of the underlying production function.[32]

The estimated impact of FDI is significant only before 1994. In column (2), the magnitude of the coefficient implies that if FDI were to increase by \$10/worker (the provincial sample mean is \$78/worker in 2003), the expected TFP growth rate would have been 0.0488 (4.9 percentage points) more per year before 1994. For the period 1994 and later, the estimated economic impact of an FDI shock is much less and not statistically significant. We conjecture that the drop in the impact of FDI after 1994 can be attributed in part to the encouragement of non-government enterprises offered by Deng Xiaoping's "South Trip". Since then, private and "red-cap" enterprises (nominally rural collectives, but in fact privately owned) and the evolution of TVEs from collectives to de facto private firms have become relatively more important sources of growth, while the relative importance of FDI-led growth has declined. Consistent with this conjecture, Wen (2007) reports that at least since the mid 1990s, FDI has tended to crowd out domestic investment, more so in the non-coastal regions. A similar finding is reported for the early 2000's by Ran, Voon, and Li (2007).

The estimated direct effect of human capital is positive and significant for both measures of the highly educated group. In column (3), where the schooling category is workers who have achieved some senior high school education or above, the coefficient is smaller than that when the schooling category is workers who have achieve some college education or above in column (2). This result is reasonable because college education should be able to contribute more to innovation and technology adaptation than education at senior high level. In column (3), the coefficient of this schooling variable

[32] The 2SLS regression results reported in tables 4-5 are robust to the use of a number of production function specifications other than those reported in table 3.

implies that if the proportion of workers with some senior high school or more education in the population increases by one-percentage point, TFP growth increases by about 0.68 percentage point a year. This is a "large" impact, but Table 1 shows that a schooling shock of 1 percentage point is also large. The average annual increase in the proportion of workers in this group is merely 0.18 percentage points between 1982 and 1993. The growth rate of the proportion of workers with some senior high school or above increased after 1994, but the annual increase remained below one percentage point on average. As can be seen, the annual increase of the proportion of workers with some college or above education is even slower. Given the rather small within-sample "shocks" that our estimates are based on, a note of caution is called for in deriving policy implications, because policies that create "large" increases in the proportion of highly educated workers will be significantly out of the range of our sampled variation and thus subject to associated larger forecast errors.

The indirect effect of human capital operating through technology spillover is modeled in the spillover variable, and the estimated effect is positive and significant. The estimated impact prior to 1994 is greater. As hypothesized, the vintage of capital measured by the acceleration of new investment has a positive effect on TFP growth, consistent with the hypothesis that new capital embodies technological change, but the estimates are not statistically significant by conventional standards in column (3). The estimated coefficient of the proportion of the workforce in non-state enterprises, a proxy for the private sector, is positive but insignificant across all specifications.

Table 5 differs in 3 ways from Table 4: (i) two measures of physical infrastructure capital are included in all regressions; (ii) we include an additional lagged variable for the direct effect of the schooling variable in one regression to test for the lasting effect of human capital; (iii) the lagged dependent variable is included in one regression to test for possible dynamic effects. In Table 5, the education level above junior high school is used to measure human capital. When we use the variable defined as some college education or above, it is insignificant in all specifications. One possible reason is the higher level of multicollinearity due to the correlation of human capital and infrastructure; and another possible reason, as discussed above, is that the proportion of college educated is too small and thus we may not detect its effect.

Compared to Table 4, the estimated impact of FDI in Table 5 is somewhat smaller. Another difference is that the impact of human capital in Table 5 is smaller when infrastructure is included, although still highly significant. The human capital spillover effect, is not statistically significant before 1994 than afterward. The second-lagged schooling variable has a smaller and insignificant effect on TFP growth than does the single-lagged variable. The estimated impact of capital vintage is generally insignificant.

We represent local infrastructure capital with two variables, telephone ownership and length of roads and highways relative to surface area of a province. Telephone intensity can be viewed as a proxy of telecommunication infrastructure, while road intensity represents transportation infrastructure. The telephone ownership rate has a positive and significant estimated effect on TFP growth, but road intensity does not. The somewhat surprising result for road infrastructure could be due to a number of reasons. For example, given that road intensity can only change slowly over time, it is possible that it may be highly correlated with the fixed effects and thus becomes insignificant in the model. In fact, the coefficient of variation at the national level from 1985 to 2003 is merely 0.2, and it is even smaller for some provinces, for example, for the northeast region it is only 0.1. Another problem is that our data measure only road length, not road quality. Unfortunately it would be a major research project in itself to get more complete data on road quality (width, average speed, etc.).[33] The regression reported in column (4) includes the lagged dependent variable. The estimated coefficient is insignificant, however.

We draw the following conclusions regarding the estimation results of alternative specifications and estimation procedures for the TFP growth equation. First, FDI has a much larger effect on TFP growth before 1994. After 1994, its effect is much smaller or statistically insignificant, and we attribute this to the growing role of locally produced growth engines in China's economic progress. Second, the direct effect of human capital measured by the proportion of workers with greater than junior high school education is

[33] An anecdote illustrates this point. One of the authors journeyed by car from Hangzhou to Wenzhou in the summer of 2007, and one of his traveling companions noted that the approximately 4-hour travel time had until recently been about twice as long. This improvement would not be reflected in our highway length variable, as the improvement resulted mainly from converting the traditional highway to motorway status.

positive. Third, the spillover effect of human capital on TFP growth is positive and statistically significant. There is no strong evidence that the spillover effect is larger before 1994. Fourth, capital vintage always has positive but mostly statistically insignificant effect on TFP growth. Finally, telecommunication infrastructure as measured by telephone intensity has had a positive and significant effect on TFP growth. The estimated coefficients for road intensity, on the other hand, are negligible.

6. Policy Implications

In order to illustrate the economic importance of our estimation results, we calculate the impacts of possible policy interventions through human capital and infrastructure investments. An output-maximizing policy maker would rely on rates of return in designing an optimal investment policy, and knowledge of these returns can be derived from the results of studies such as ours. We estimate the internal rates of return to investment in education and telecommunication infrastructure with telephones as a proxy. The internal rate of return is calculated by equalizing the estimated cost to the present value of estimated future benefits as reflected in the contribution to TFP growth or directly to production.[34] As in most cost-benefit analyses based on behavioral data, the rates of return we calculate are no more precise than the estimated coefficients on which they are based and should be interpreted with this uncertainty in mind. Nevertheless, they are the best estimates available to us as a guide to intelligent policy formation.

6.1 Rates of Return[35]

The returns to senior high school education and infrastructure are assumed to emanate from their impacts on TFP growth, while the return to junior high school

[34] We do not compute the internal rates of return to road construction because the coefficient estimate of road construction is mostly insignificant.

[35] In Table 6, we report the rates of return to investment in education and telecommunications infrastructure based on the production function (4) from Table 3 and the TFP growth regression (2) from Table 5. As a robustness check, we compute the rates of return based on various types of the production function, namely (2), (3) and (5) from Table 3 (we skip the production function (1) because of its negative coefficient of low-skilled labor). The results based on (3) and (5) are quantitatively similar to the ones reported in Table 6. The results based on (2) are also similar except for the rates of return to investment in education based on the direct contribution, which are about twice higher than the ones in Table 6, but the qualitative conclusion is still well maintained. Those results are available upon request.

education is postulated to arise from its direct impact as a factor of production. We develop simple approaches to estimate the costs of these investments. We are relatively more confident in our ability to measure the costs of human-capital investment than of infrastructure investment, because the costs of investing in communications equipment are less well represented in official data. Therefore, we believe that our returns estimates are more reliable for regional comparison than for comparing the relative payoffs to human-capital versus infrastructure-capital investments.

In estimating the return to education based on its direct contribution on the production process, we assume that some of workers from the low schooling (L_n) group are advanced to the high schooling (L_e) group through an adult education program. In estimating the portion of the return to education that comes from its indirect contribution through TFP growth on the production process, we assume that some of the workers with only junior high school education are selected to obtain higher levels. Costs of education consist of two components: foregone production while a worker is taken out of production and sent to school and the direct costs of teachers, administrators, "bricks and mortar," and other direct expenses of schooling. Details of estimating the internal rates of return to human capital and infrastructure are given in Appendices A-C of an earlier version of this paper (Fleisher, Li, and Zhao, 2008) which can be accessed via the internet.

The calculated internal rates of return to education are reported for each region in Table 6, columns (1) and (2). Column (1) contains the estimated rates of return to providing schooling above the elementary level, which occurs directly in the production process.[36] The national average rate of return is approximately 14.4%, and it is much higher in the far west and interior regions (about 18.5% and 18.6%, respectively) than in the coastal and northeast regions (about 12% and 8.4%, respectively). All of these estimates are much higher than the 7% return to education in production assumed by Bosworth and Collins (2008) in their work comparing TFP growth in China and India

[36] We assume that the proportional distribution of education outcomes above elementary matches the current distribution. That is, the likelihood that a student taken from the elementary group will complete junior high school, senior high school, or college matches the current distribution of these schooling levels in the population. The rate of return estimates are quite robust to using the coefficients from any of the production function specifications that yield a significant estimated coefficient for less-educated workers.

through 2004. Moreover, they are higher and more consistently estimated than those obtained in cross-country research (Pritchett, 2006).

It is instructive to compare the estimated rates of return in Table 6 with the marginal products of educated labor shown in Figure 5. It is clear that at existing factor quantities, the marginal product of educated labor is much higher in the coastal region and northeast regions than elsewhere, but so is the marginal product of less-educated labor. Hence the opportunity cost of sending a coastal or northeast worker to school is higher than it is in the interior or far west regions. Moreover, the marginal product of the less-schooled group in the coastal and northeast regions has accelerated relative to that in the west and far west since the mid- to late 1990s.

The calculated rate of return per year of additional schooling to investment in education above junior high school based on its contribution to TFP growth is reported in column (2a) of Table 6. It is based on the 2SLS estimates reported in column (4) of Table 5. The national average rate of return is approximately 26.8%. The interior region has the highest return of 28.2%. A more complete estimate of the return to investment in schooling is obtained if we combine the direct and indirect effects. Obviously, the sign of the net outcome on the return to schooling is ambiguous, and this ambiguity is illustrated in column 2b, where the combined direct and indirect impacts decrease for the economically advanced regions (where the marginal product of less-educated labor is relatively high) and increase for the interior and far west regions. The combined effect is highest in the interior, followed in decreasing order by the coastal, far west and northeast regions.[37] Again, the indirect returns we estimate for China are higher and more consistently estimated than those obtain in most cross-country studies (Pritchett, 2006).

Column (3) in Table 6 contains the calculated rates of return for investment in telecommunications infrastructure based on its contribution to TFP growth. The assumptions and methods used are detailed in Appendix D. We assume zero maintenance costs and thus may overestimate the rates of return. The national average

[37] It might be argued that the rates of return calculated from our data are not good estimates of the treatment effect of providing more schooling to the regional populations, because of selection and sorting biases (Heckman and Li, 2004). However, such biases should be mitigated in this study insofar as the distributions of individual comparative advantages within provinces are similar across provinces. Moreover, there is evidence that finance constraints are important in determining the level of schooling attainment in China (Heckman, 2005; Wang, Fleisher, Li, and Li, 2008).

rate of return to investment in telecommunication infrastructure is over 46%.[38] The return ranges from nearly 57% in the coastal region to approximately 38% in the far west. Unlike the return to human capital investment in production, the investment in telecommunication infrastructure appears to be positively correlated with local development, being higher in the relatively developed northeast and coastal regions. We conjecture that this regional pattern is attributable to scale effects, and it implies that infrastructure investments directed toward regions with the highest returns are not likely to reduce regional inequality. Rather they are likely to increase regional disparities. Human capital investment, however, generates higher or comparable return in less-developed regions than that in developed regions. Therefore, although both policies have a high impact on growth, investing in human capital would be a more effective policy to reduce regional income gaps.

6.2 Hypothetical Policy Experiments

Given that the starting point of this paper was the observation that regional inequality in China has soared, it is interesting to perform a hypothetical policy experiment. Suppose, for example, that the central government were to invest in human capital or telecommunication infrastructure in the northeast, far west and interior regions in order to reduce the regional per-capita output gaps. We assume that there are five phases in this hypothetical investment project (each phase lasts a year). In each phase, the central government would distribute 10% of their annual revenue to the non-coastal regions (weighed by their population size) to carry out the investment project. The first investment would yield returns starting in 2004, and the last investment would yield returns in 2008.

We analyze two scenarios: (1) allocation to increase the number of students advancing beyond elementary school, distributed in proportion to the current distribution of schooling in the workforce within each region; (2) investment in telecommunications infrastructure. Assume the burden of the tax is on consumption expenditure in the year it is imposed. We use the regression results underlying the rate of return estimates reported

[38] Given the difficulty in estimating the cost of infrastructure and education, we do not compare the rates of return between different types of investment.

in Table 6 to discuss these policy alternatives in terms of their ability to reduce regional inequality over a 10-year horizon through 2013. Details of the derivations and calculations are reported in appendix E. Table 7 shows the impacts of these alternative projects. In our calculation of policy impacts, we ignore the deadweight loss that would be associated with almost any tax-redistribution policy. Calculation of such losses and comparing them with possible policy gains is beyond the scope of this paper, although a worthwhile endeavor for future research.

The first line of each cell in Table 7 is the predicted ratio of per-capita GDP in one of the other three regions to the coastal region if one of the three policy actions is undertaken.[39] The last row shows the predicted regional GDP ratio if no policy is undertaken, and the second line of each cell is the difference between the no-policy ratio and the ratio under a given policy. Finally, the third line in each cell shows the percentage decline in the provincial GDP ratio under each policy. For example, the number 0.537 in the first line of the last column indicates that a policy of increasing schooling above the elementary level in the interior region, with no change in the coastal region, would increase the interior/coast inequality ratio from 0.409 to 0.537, or by approximately 31.3% of the 2003 ratio by the year 2013. In the first row, we see that the impact of a policy focused on raising schooling levels education would have a substantially larger impact on reducing regional inequality in the interior than in far west. The same policy applied to the northeast region would reduce the income gap by only about 7.9%. In the second row of Table 7, we see that investment in telecommunication infrastructure would reduce the income gap by about 33.6% across all three non-coastal regions.

7. Conclusion and Recommendations

China's spectacular economic growth has benefited its provinces and regions quite unequally. China has not only one of the highest rates of economic growth but also one of the highest degrees of regional income inequality in the world. We investigate the determinants of the regional dispersion in rates of economic growth and TFP growth. We

[39] The policy actions are applied only to the non-coastal regions. The 2013 per-capita GDP in the coastal region is predicted without any policy intervention.

hypothesize that they can be understood as a function of several interrelated factors, which include investment in physical capital, human capital, and infrastructure capital; the infusion of new technology and its regional spread; and market reforms, with a major step forward occurring following Deng Xiaoping's "South Trip" in 1992 and following the serious budget-constraint hardening that occurred in 1997 and subsequent years.

Our empirical results are robust to alternative model specifications and estimation methods. First, FDI had much larger effect on TFP growth before 1994. After 1994, its effect becomes negligible. The diminished impact of FDI in the later stage of economic transition is consistent with the hypothesis that the acceleration of market reforms reduced the impact of FDI on technology transmission, not because technological advance became less important, but because the channels of its dissemination became more diffuse. We find that telecommunication infrastructure, which we measure by the intensity of urban telephone subscribers, has a positive effect on TFP growth, but that the impact of transportation infrastructure, which we measure by road intensity, is imprecisely estimated.

We find that human capital positively affects output in three ways. First, educated labor makes a direct contribution to production. Workers with more than elementary school education have a much higher marginal product than labor with no higher than elementary schooling. Second, we estimate a positive, direct effect of human capital (measured by the proportion of workers with some senior high school education or above) on TFP growth. This direct effect is hypothesized to come from domestic innovation activities. Third, we present evidence of an indirect spillover effect of human capital on TFP growth.

We derive cost-benefit analysis of possible policies to raise GDP using an internal rate of return metric and obtain results from a policy "experiment" in which we project the impact of increases in human capital and infrastructure capital on regional inequality. We find that, while investment in infrastructure generates higher returns in the developed regions, investing in human capital generates higher or comparable returns in less-developed regions. Therefore, we conclude that human capital investment in less-developed areas can achieve economic efficiency and reduce inequality. We present these estimates as our best effort to construct a framework for the formulation of beneficial policies. The robustness of our estimation results to alternative specifications makes us reasonably confident that our estimated returns to investment, particularly in human capital, would not seriously mislead policy makers.

Based on the policy impacts reported in Table 7, we find the following results. (1) The interior region would gain substantially relative to the coast from increasing both the stock of human and infrastructure (telecommunications) capital. (2) The far west would also experience a significant gain in relative GDP per capita. (3) The gain for all three regions would be similar from infrastructure investment.

We find evidence that China's transition toward a market economy accelerated after 1994. But Chinese policy makers face a dilemma, because continued economic transformation has not been equally beneficial across China's major regions. The interior region (near west) and far western regions lag far behind the coastal and northeast regions in economic progress. There is an important implication of our research findings for China's on-going Go-West, formally known as the "Grand Western Development" Project, which was launched in 2000. It encompasses eleven provinces including the entire far west region as defined in this paper and five provinces in our interior region. The largest part of expenditure mandating from this project is focused on investment in infrastructure. Between 2000 and 2005, the cumulative investment in infrastructure was about 1 trillion Yuan (about US$121 billion).[40] The results of our research imply that, it is important to put human capital investment on an equal footing in this project, both for reasons of economic efficiency and for reducing inequality.

[40] http://cppcc.people.com.cn/GB/34961/70385/70386/4783169.html [Access Date: January 23, 2007].

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Table 1
High School and College Graduates (%)

	Some Senior high School or Above / Population					Some College or Above / Population				
	Coastal	Northeast	Far West	Interior	National	Coastal	Northeast	Far West	Interior	National
1982	8.28	10.54	6.68	5.95	7.19	0.74	0.86	0.61	0.46	0.60
1983	8.70	11.15	7.04	6.23	7.55	1.07	1.41	0.94	0.67	0.88
1984	8.95	11.62	7.54	6.47	7.82	1.12	1.47	0.97	0.70	0.92
1985	9.22	12.13	8.06	6.72	8.11	1.18	1.54	1.02	0.73	0.97
1986	9.47	12.58	8.57	6.95	8.38	1.23	1.61	1.05	0.76	1.01
1987	9.71	12.96	9.06	7.17	8.63	1.28	1.68	1.08	0.80	1.05
1988	9.95	13.31	9.53	7.37	8.86	1.34	1.75	1.12	0.83	1.10
1989	10.17	13.60	9.96	7.58	9.09	1.39	1.80	1.15	0.86	1.13
1990	10.35	14.02	10.09	7.78	9.30	1.66	2.33	1.42	1.05	1.39
1991	9.30	12.88	8.97	7.10	8.43	1.52	2.22	1.38	0.94	1.27
1992	9.60	13.26	9.32	7.36	8.72	1.58	2.30	1.41	0.98	1.32
1993	8.66	12.14	8.18	6.73	7.92	1.48	2.22	1.39	0.89	1.23
1994	9.86	13.88	10.06	7.79	9.12	1.82	2.77	2.08	1.25	1.61
1995	10.28	14.28	10.34	8.12	9.48	1.89	2.86	2.10	1.30	1.67
1996	11.50	15.85	12.18	9.17	10.67	2.22	3.37	2.77	1.65	2.04
1997	13.54	17.69	12.25	10.23	12.09	2.80	4.97	2.82	1.92	2.52
1998	14.35	17.09	12.54	10.52	12.48	3.15	4.24	3.17	1.91	2.59
1999	14.97	17.23	14.51	10.60	12.83	3.52	4.54	3.98	2.10	2.87
2000	16.61	19.01	14.03	12.27	14.46	4.09	5.30	3.55	2.77	3.49
2001	18.16	19.13	15.55	12.80	15.31	4.89	5.26	4.41	3.06	3.94
2002	19.11	19.29	16.75	13.56	16.10	5.59	5.28	5.21	3.45	4.42
2003	20.27	21.32	17.39	15.52	17.73	6.20	6.58	6.00	4.19	5.17

Notes:
1. Tibet is excluded for lack of continuous data.

Table 2a
Summary Statistics - 1985
Mean (Standard Deviation)

Variable	1985 Coastal	Northeast	Far West	Interior	National
GDP	622.75	547.48	116.05	464.61	474.53
(100,000,000 yuan)	(284.34)	(241.10)	(73.06)	(235.48)	(280.07)
Capital	1081.91	1386.15	216.78	914.22	919.05
(100,000,000 yuan)	(546.06)	(600.75)	(102.67)	(654.97)	(630.22)
Less-educated workers, elementary or below	1107.22	596.67	317.17	1405.07	1067.31
(10,000 workers)	(816.84)	(136.38)	(291.05)	(835.83)	(807.66)
Educated workers, some junior high school education or above	854.54	732.96	184.66	747.65	700.00
(10,000 workers)	(446.34)	(286.95)	(147.08)	(394.38)	(423.48)
FDI / total workforce	14.70	0.52	0.21	0.45	5.01
(1 US dollars per worker)	(24.48)	(0.45)	(0.15)	(0.47)	(14.96)
Human-capital spillover	0.22	0.10	0.09	0.18	0.17
	(0.23)	(0.04)	(0.05)	(0.09)	(0.14)
Capital vintage	0.0092	0.0103	0.0147	0.0036	0.0077
	(0.01)	(0.01)	(0.02)	(0.01)	(0.01)
Urban telephone subscribers / population	5.70	3.75	2.69	1.54	3.28
(1 subscriber/ 1000 person)	(5.66)	(0.66)	(0.80)	(0.71)	(3.63)
Roads / area	0.30	0.15	0.05	0.18	0.20
(km length per km^2)	(0.09)	(0.07)	(0.04)	(0.06)	(0.11)
Urban non-state workforce / total workforce	20.67	23.05	2.27	1.96	10.28
(1 person / 10000 persons)	(13.71)	(36.33)	(1.24)	(1.89)	(15.79)
Zone1	1.33	0	0	0.08	0.46
	(1.66)	.	.	(0.29)	(1.10)
Zone2	1.22	0.33	0	0	0.43
	(0.67)	(0.58)	.	.	(0.69)
Zone3	0.56	0	0	0	0.18
	(1.33)	.	.	.	(0.77)

Notes:
1. All the monetary values were deflated with the base of Beijing 1990. The means are the provincial average, and the Standard deviations are in the parentheses.
2. Hainan is included in Guangdong; and Chongqing is included in Sichuan. Tibet is excluded for lack of continuous data.
3. Human-capital spillover and Capital vintage is defined in the text. .
4. "Urban non-state workforce" are employed in share holding units, joint ownership units, limited liability corporations, share-holding corporations, and units funded from abroad, Hong Kong, Macao and Taiwan.
5. Zone1 represents the total number of Opening Cities in a province; Zone2 is the total number of Duty-Free Cities, High-Tech, or Economic Development Cities or Zones in a province, and Zone3 is the number of National Special Economic Zones in a province.

Table 2b
Summary Statistics - 1994
Mean (Standard Deviation)

Variable	Coastal (1994)	Northeast (1994)	Far West (1994)	Interior (1994)	National (1994)
GDP	1790.38	1140.95	263.73	1008.58	1167.65
(100,000,000 yuan)	(984.07)	(522.66)	(195.26)	(517.53)	(825.93)
Capital	2924.61	2522.14	562.89	1807.05	2065.15
(100,000,000 yuan)	(1385.08)	(1043.59)	(352.57)	(1037.42)	(1317.10)
Less-educated workers, elementary or below	1152.09	534.92	321.34	1515.77	1123.15
(10,000 workers)	(882.96)	(102.36)	(262.93)	(863.82)	(863.67)
Educated workers, some junior high school education or above	1258.13	1059.64	243.44	1202.64	1068.12
(10,000 workers)	(715.30)	(282.32)	(182.17)	(673.56)	(683.27)
FDI / total workforce	157.67	35.79	7.21	11.71	60.56
(1 US dollars per worker)	(118.34)	(24.52)	(8.09)	(7.81)	(94.45)
Human-capital spillover	0.16	0.12	0.14	0.22	0.18
	(0.16)	(0.05)	(0.06)	(0.10)	(0.12)
Capital vintage	0.0105	-0.0008	-0.0016	0.0025	0.0041
	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)
Urban telephone subscribers / population	46.32	30.35	14.31	11.21	24.99
(1 subscriber/ 1000 person)	(37.47)	(3.48)	(3.59)	(3.54)	(26.07)
Roads / area	0.40	0.18	0.06	0.20	0.24
(km length per km^2)	(0.15)	(0.10)	(0.05)	(0.07)	(0.16)
Urban non-state workforce / total workforce	334.34	170.94	33.69	47.32	150.88
(1 person / 10000 persons)	(228.57)	(83.00)	(27.82)	(28.68)	(185.68)
Zone1	1.44	2.33	1.25	0.75	1.21
	(1.51)	(1.53)	(1.26)	(1.36)	(1.42)
Zone2	3.33	2.67	0.50	1.67	2.14
	(2.60)	(1.15)	(0.58)	(0.65)	(1.82)
Zone3	0.67	0	0	0	0.21
	(1.32)	.	.	.	(0.79)

See note in table 2a

Table 2c
Summary Statistics - 2003
Mean (Standard Deviation)

	2003				
Variable	Coastal	Northeast	Far West	Interior	National
GDP	4807.25	2525.77	586.49	2381.41	2920.19
(100,000,000 yuan)	(2648.19)	(1082.18)	(412.06)	(1224.35)	(2221.34)
Capital	7899.16	4163.88	1208.88	3836.44	4802.03
(100,000,000 yuan)	(3708.76)	(1525.63)	(796.81)	(2242.13)	(3454.90)
Less-educated workers, elementary or below	781.39	363.99	288.59	1149.39	823.98
(10,000 workers)	(590.34)	(71.72)	(240.15)	(666.37)	(636.08)
Educated workers, some junior high school education or above	1784.39	1145.45	353.96	1729.08	1487.88
(10,000 workers)	(1101.59)	(356.09)	(258.45)	(1012.58)	(1026.04)
FDI / total workforce	193.84	48.51	3.80	17.03	75.35
(1 US dollars per worker)	(151.44)	(58.74)	(2.93)	(18.81)	(119.27)
Human-capital spillover	0.23	0.17	0.23	0.43	0.31
	(0.19)	(0.04)	(0.09)	(0.23)	(0.21)
Capital vintage	0.0011	0.0008	0.0003	0.0069	0.0034
	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)
Urban telephone subscribers / population	243.07	180.78	128.75	96.97	157.45
(1 subscriber/ 1000 person)	(124.35)	(31.45)	(22.32)	(26.16)	(96.13)
Roads / area	0.65	0.24	0.09	0.34	0.39
(km length per km^2)	(0.25)	(0.10)	(0.07)	(0.13)	(0.26)
Urban non-state workforce / total workforce	1047.43	627.03	409.52	291.14	587.13
(1 person / 10000 persons)	(754.43)	(89.06)	(266.58)	(136.30)	(546.91)
Zone1	1.56	2.33	0.75	0.67	1.14
	(1.59)	(1.53)	(1.50)	(1.23)	(1.46)
Zone2	3.33	2.67	1.25	1.83	2.32
	(2.60)	(1.15)	(0.50)	(0.72)	(1.72)
Zone3	0.67	0	0	0	0.21
	(1.32)	.	.	.	(0.79)

See note in table 2a

Table 3
Production Function Estimates 1985-2003

Dependent variable: log(GDP_t)	(1) 2-Way FE with year and provincial. dummies	(2) 2-Way FE plus Region*annual time dummy	(3) 2-Way FE plus Province* time dummy = 1 after 1996	(4) 2-Way FE with E_{it}^{a}	(5) 2-Way FE with E_{it}^{b}
log($Capital_t$)	0.403*** (0.027)	0.183*** (0.027)	0.450*** (0.051)	0.528*** (0.030)	0.487*** (0.042)
log(Educated worker)	0.282*** (0.073)	0.326*** (0.069)	0.236** (0.100)	0.421*** (0.057)	0.320*** (0.082)
log(Less-educated worker)	-0.103 (0.064)	0.039 (0.053)	0.063* (0.037)	0.108*** (0.028)	0.083** (0.030)
N	28	28	28	28	28
T	19	19	19	19	19
Within R-square	0.984	0.991	0.991	0.992	0.991
F Test for No Fixed Effects: F Value (Pr > F)	333.66 (<0.0001)	264.22 (<.0001)	455.48 (<.0001)	323.92 (<.0001)	269.02 (<.0001)

Notes:
1. Hainan is included in Guangdong; and Chongqing is included in Sichuan. Tibet is excluded for lack of continuous data.
2. Robust standard errors are in the parentheses. The stars *, ** and *** indicate the significance level at 10%, 5%, and 1%, respectively.
3. "GDP": 100,000,000 yuan. "Capital": 100,000,000 yuan. "Educated worker": 10,000 workers. "Less-educated workers": 10,000 workers. All the monetary values were deflated with the base of Beijing 1990.

Table 4
TFP growth regressions without infrastructure variables, 1988-2003

Dependent variable: $\log(TFP_t) - \log(TFP_{t-1})$	Two-Way FE	Two-way FE + 2SLS	
	(1) PF table 3(4)	(2) PF table 3(4)	(3) PF table 3(4)
FDI_{t-2}	0.077 (0.061)	0.285 (0.181)	0.266 (0.178)
FDI_{t-2} * Year 1994	0.779^{*} (0.395)	4.609^{**} (1.926)	4.637^{**} (1.937)
Some college or above $_{t-1}$	0.238 (0.212)	0.919^{*} (0.542)	
Some senior high school or above $_{t-1}$			0.677^{**} (0.265)
Human capital spillover $_{t-2}$	0.480^{**} (0.196)	0.523^{**} (0.215)	0.196^{***} (0.069)
Human capital spillover $_{t-2}$ * Year 1994	0.238 (0.252)	0.661^{**} (0.313)	0.076 (0.047)
Capital Vintage $_t$	0.251^{*} (0.144)	0.349^{*} (0.185)	0.249 (0.179)
Non-state $Workforce_{t-1}$	0.041 (0.216)	0.123 (0.331)	0.172 (0.256)
N	28	28	28
T	16	16	16
Within R-square	0.499	0.213	0.241
Test for No Fixed Effects: F Value (Pr > F)	12.76 (<.0001)	6.15 (<0.0001)	6.57 (<0.0001)
Test for Overidentifying Restrictions (Sargan-Hansen statistic): F Value (Pr > F)		0.02 (0.888)	0.82 (0.366)
Hausman Test for Endogeneity: F Value (Pr > F)		6.83 (0.0093)	6.99 (0.0085)

Notes:
1. Hainan is included in Guangdong; and Chongqing is included in Sichuan. Tibet is excluded for lack of continuous data.
2. Year 1994 = 1 if year < 1994; 0 otherwise.
3. Standard errors are in the parentheses. The stars *, ** and ***, indicate the significance levels at 10%, 5%, and 1%, respectively.
4. "FDI": 1,000 US dollars per worker. All the monetary values were deflated with the base of Beijing 1990. "Some college or above": the proportion of population with education that are beyond the senior high school. "Some senior high school or above": the proportion of population with education that are beyond the junior high school. "Capital Vintage": double difference of log Capital. "Human capital spillover" variable is defined in the text. "Non-state Workforce" is the proportion of urban labor employed in non-state owned firms.
5. In the 2SLS estimation, Zone1, Zone2, and Zone3 are used as instrumental variables.
6. "h" in the human capital spillover variable in Column (3) is based on "some senior high school or above."

Table 5
TFP growth regressions with infrastructure variables 1988-2003

Dependent variable: $\log(TFP_t) - \log(TFP_{t-1})$	(1) 2-way FE PF table 3(4)	(2) 2-way FE + 2SLS PF table 3(4)	(3)	(4)
FDI_{t-2}	0.083 (0.050)	0.059 (0.149)	0.093 (0.161)	0.080 (0.156)
FDI_{t-2} * Year 1994	0.868^{**} (0.367)	3.324^{**} (1.597)	3.540^{**} (1.676)	3.675^{**} (1.718)
Some senior high school or above $_{t-1}$	0.294^{**} (0.133)	0.501^{**} (0.221)	0.379^{*} (0.210)	0.497^{**} (0.226)
Some senior high school or above $_{t-2}$			0.300 (0.248)	
Human capital spillover $_{t-2}$	0.218^{***} (0.052)	0.181^{***} (0.061)	0.157^{**} (0.065)	0.208^{***} (0.066)
Human capital spillover $_{t-2}$ * Year 1994	-0.006 (0.039)	0.047 (0.040)	0.056 (0.043)	0.047 (0.041)
Capital vintage $_t$	0.201 (0.156)	0.203 (0.158)	0.219 (0.162)	0.293^{*} (0.176)
Telephones $_{t-2}$	0.312^{**} (0.137)	0.477^{***} (0.164)	0.412^{**} (0.168)	0.522^{***} (0.172)
Roads $_{t-2}$	-0.003 (0.030)	0.051 (0.048)	0.043 (0.048)	0.055 (0.050)
Non-state workforce$_{t-1}$	-0.366 (0.222)	-0.286 (0.278)	-0.306 (0.283)	-0.297 (0.285)
$\log(TFP_{t-1}) - \log(TFP_{t-2})$				-0.106 (0.066)
N	28	28	28	28
T	16	16	16	16
With R-square	0.524	0.400	0.386	0.370
Test for No Fixed Effects: F Value (Pr > F)	13.56 (<0.0001)	8.29 (<0.0001)	7.94 (<0.0001)	6.57 (<0.0001)
Test for Overidentifying Restrictions (Sargan-Hansen statistic): F Value (Pr > F)		1.546 (0.214)	1.27 (0.261)	1.55 (0.214)
Hausman Test for Endogeneity: F Value (Pr > F)		3.86 (0.05)	4.13 (0.043)	4.42 (0.036)

Notes:
1. Hainan is included in Guangdong; and Chongqing is included in Sichuan. Tibet is excluded for lack of continuous data.
2. Year 1994 = 1 if year < 1994; 0 otherwise.
3. Standard errors are in the parentheses. The stars *, ** and *** indicate the significance levels at 10%, 5%, and 1%, respectively.
5. "FDI": 1,000 US dollars per worker. All the monetary values were deflated with the base of Beijing 1990. "Some senior high school or above": the proportion of population with education that are beyond the junior high school. "Capital Vintage": double difference of log Capital. "Telephone": the proportion of urban telephone subscribers in the population. "Road": km per km^2. "Non-state Workforce" is the proportion of urban labor employed in non-state owned firms. "Human capital spillover" variable is defined in the text.
6. In the 2SLS estimation, Zone1, Zone2, and Zone3 are used as instrumental variables.

Table 6
Internal Rates of Return to Investment in Education and Telecommunications Infrastructure

Region	(1) Direct Contribution to Production via Investment in Education Higher than Elementary	(2) Investment in Education above Junior High School: (a) Indirect Contribution to Production through TFP Growth	(2) Investment in Education above Junior High School: (b) Combined Direct and Indirect Contributions	(3) Indirect Contribution to Production through TFP Growth via Telecommunication Investment
Coastal	0.123	0.280	0.260	0.566
Northeast	0.084	0.277	0.237	0.525
Far West	0.185	0.232	0.259	0.378
Interior	0.186	0.282	0.289	0.390
National	0.144	0.268	0.261	0.465

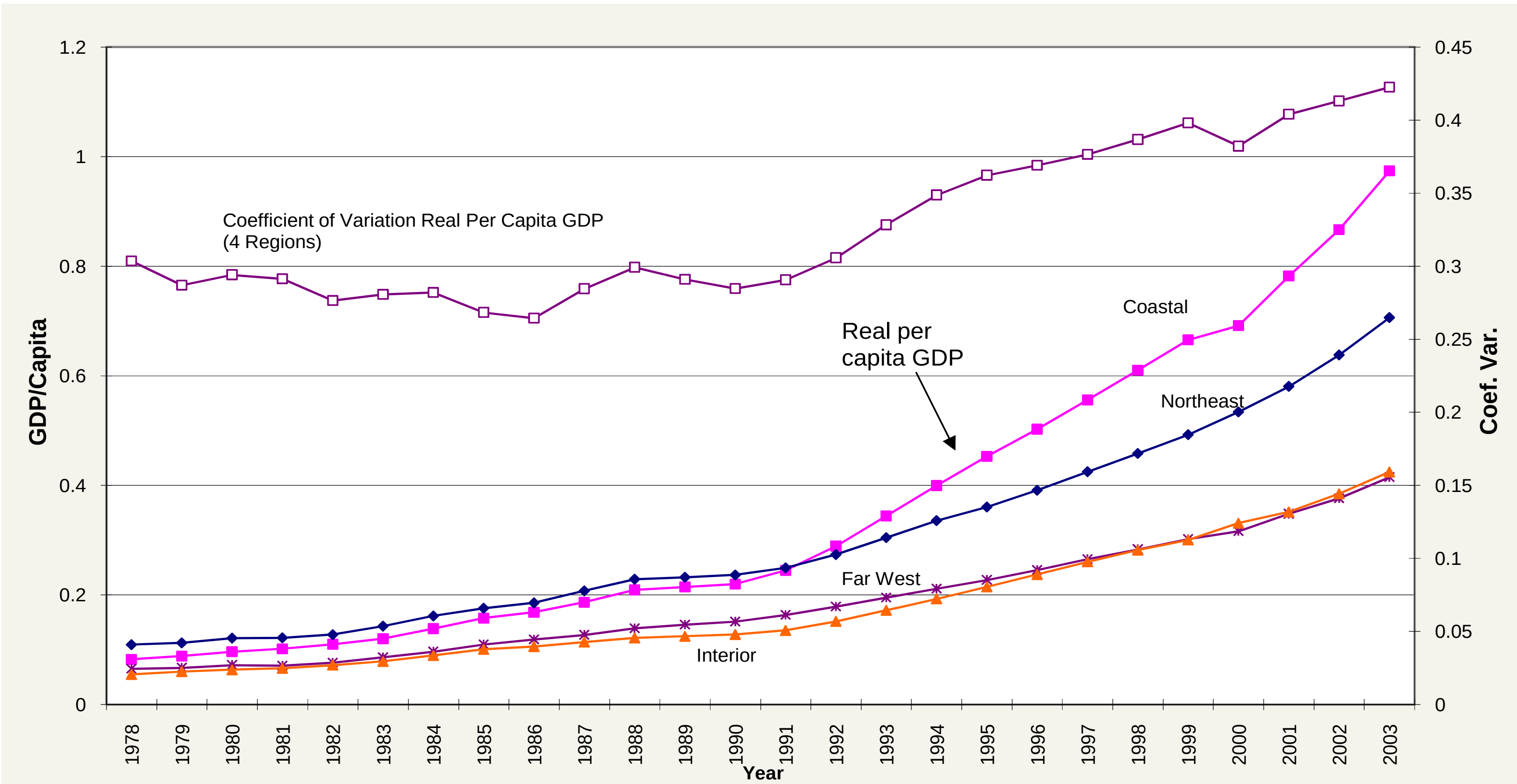
Note:
1. Production function: (4) in table 3; TFP growth regression: (2) in table 5.
2. The derivations of the rates of return (ρ_i^s) are provided in Appendix A-D.
3. National calculations are arithmetic means of the constituent regions.

Table 7
Impact on Regional Ratios of Per-Capita GDP under Alternative Hypothetical Policy Scenarios in 2013

	NE/Coastal	FW/Coastal	Interior /Coastal
Human Capital (Direct + Indirect Contribution)	0.955	0.465	0.537
Increase compared to No Policy	0.070	0.090	0.128
% of Increase in the Ratios	7.9%	24.0%	31.3%
Telecommunication	1.183	0.501	0.546
Increase compared to No Policy	0.297	0.126	0.137
% of Increase in the Ratios	33.6%	33.6%	33.6%
Predicted ratios without any policy imposed	0.885	0.375	0.409

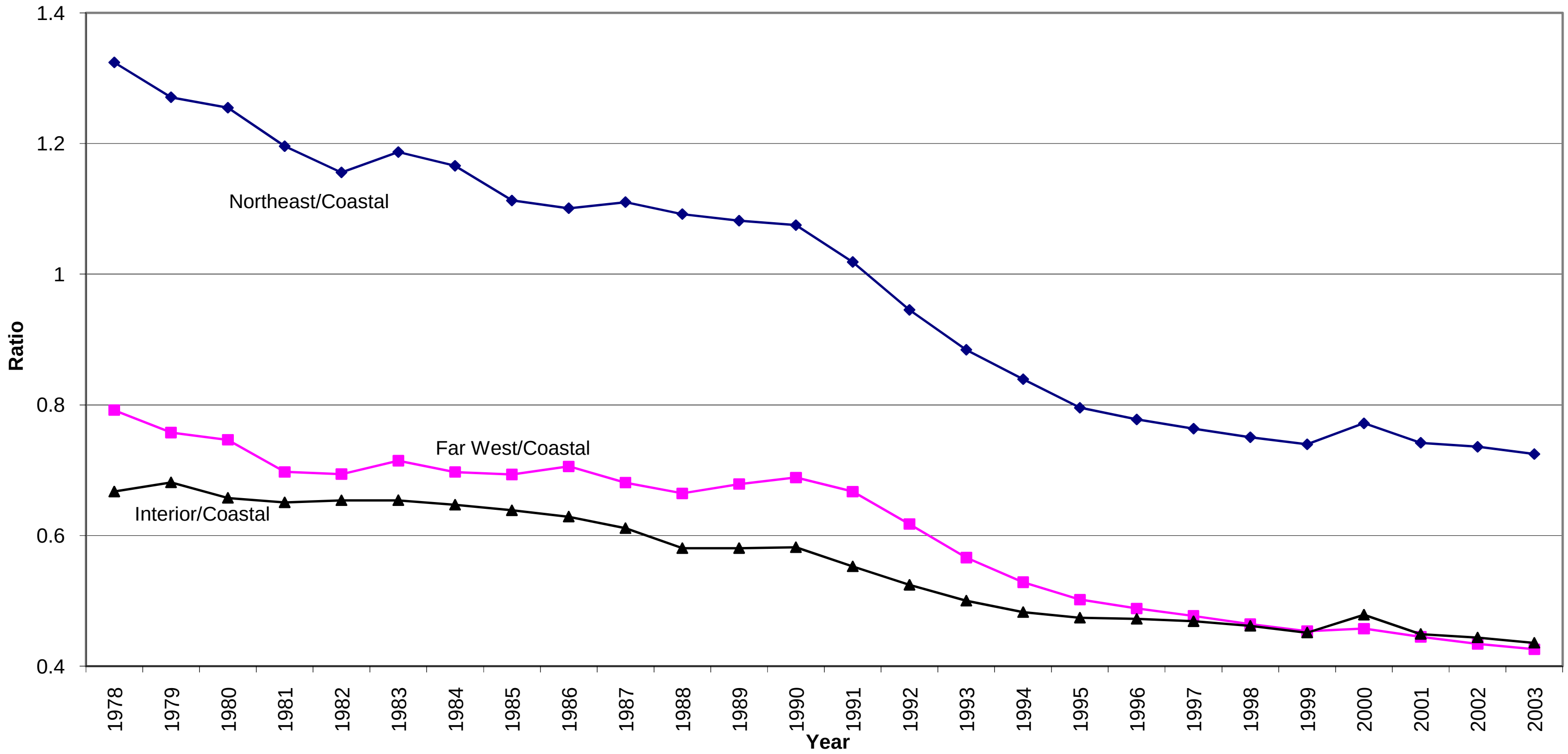
Notes:
1. Full details of the derivation are provided in Appendix E.
2. For Telecommunication, the percentages of increase in the ratios are identical across regions. The reason is as follows. The formula for computing "% of Increase in the Ratios" for Telecommunication is $\exp(\beta^t \cdot z \cdot g_i / Population_i) - 1$. β^t (from the TFP growth equation) and z (function of depreciation) are constants. The variable g_i is the increase in the telecommunication infrastructure in each phase of the investment project. Since the investment funding received by each region is distributed according to its population size and the unit cost of telecommunication is set to be the same across regions, $g_i/Population_i$ will be identical across regions.

Figure 1 Real GDP per Capita (RMB 10,000 Yuan in 1990 Beijing value)



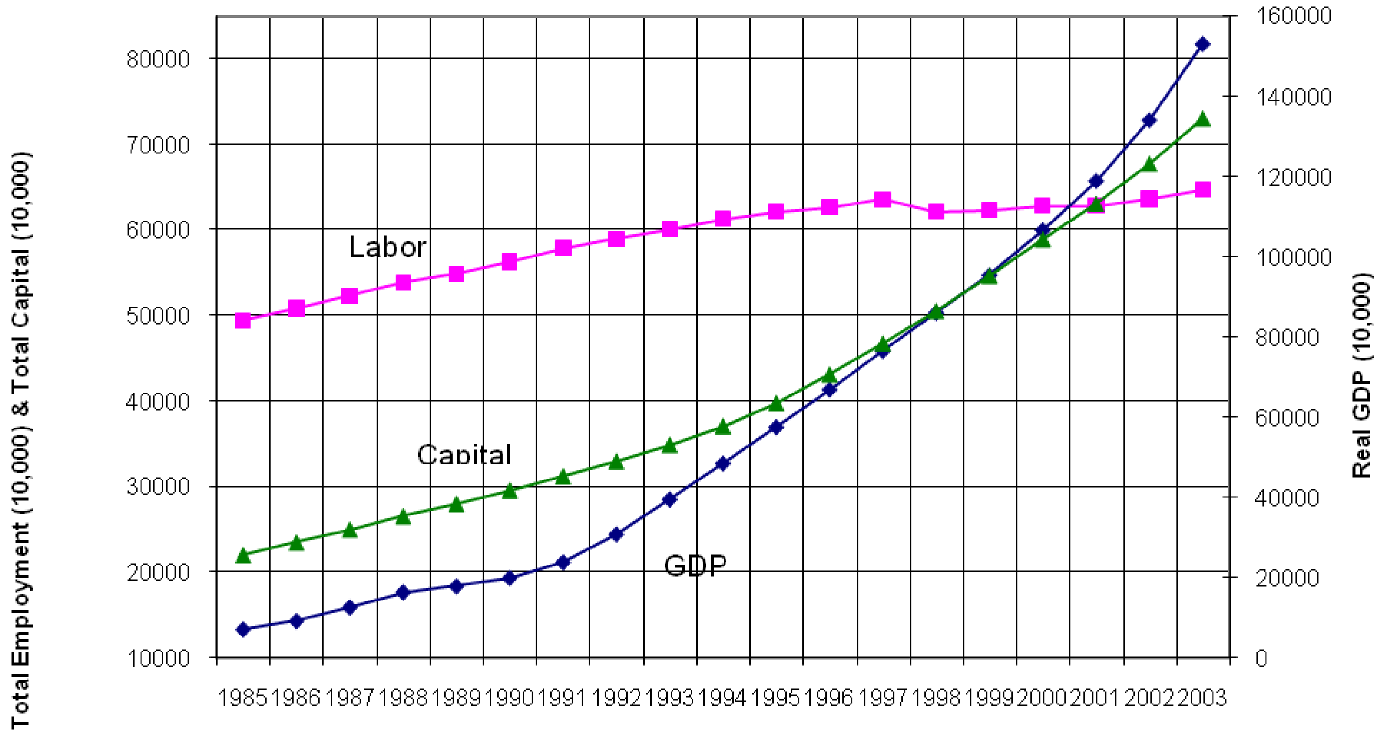
Sources of data: various years of the China Statistical Yearbook and China Data Online (2008).

Figure 2 Real Per Capita GDP Regional Ratios to Coast



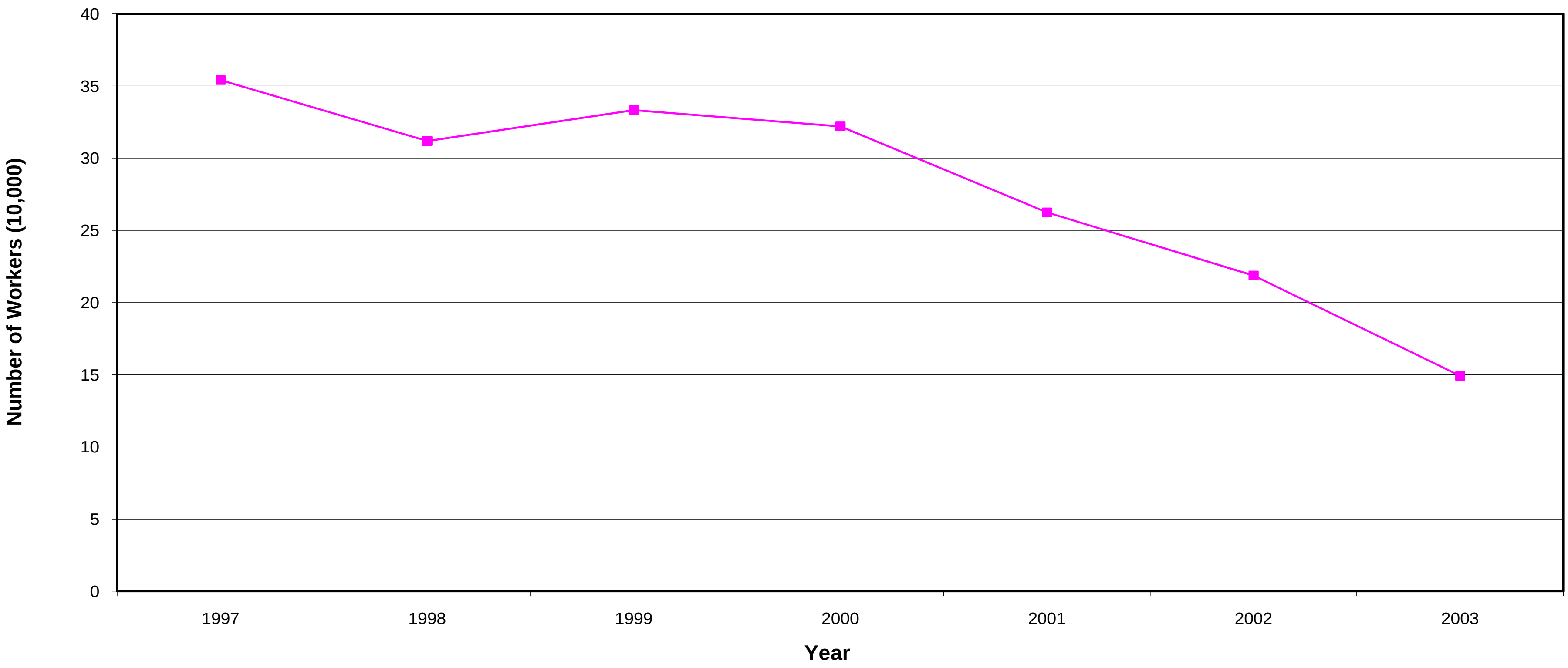
Sources of data: various years of the China Statistical Yearbook and China Data Online (2008).

Figure 3 Labor, Capital and Real GDP



Notes:
1. Sources of data: various years of the China Statistical Yearbook and China Data Online (2008).
2. The capital stock was estimated using Holz's (2006) cumulative investment approach.

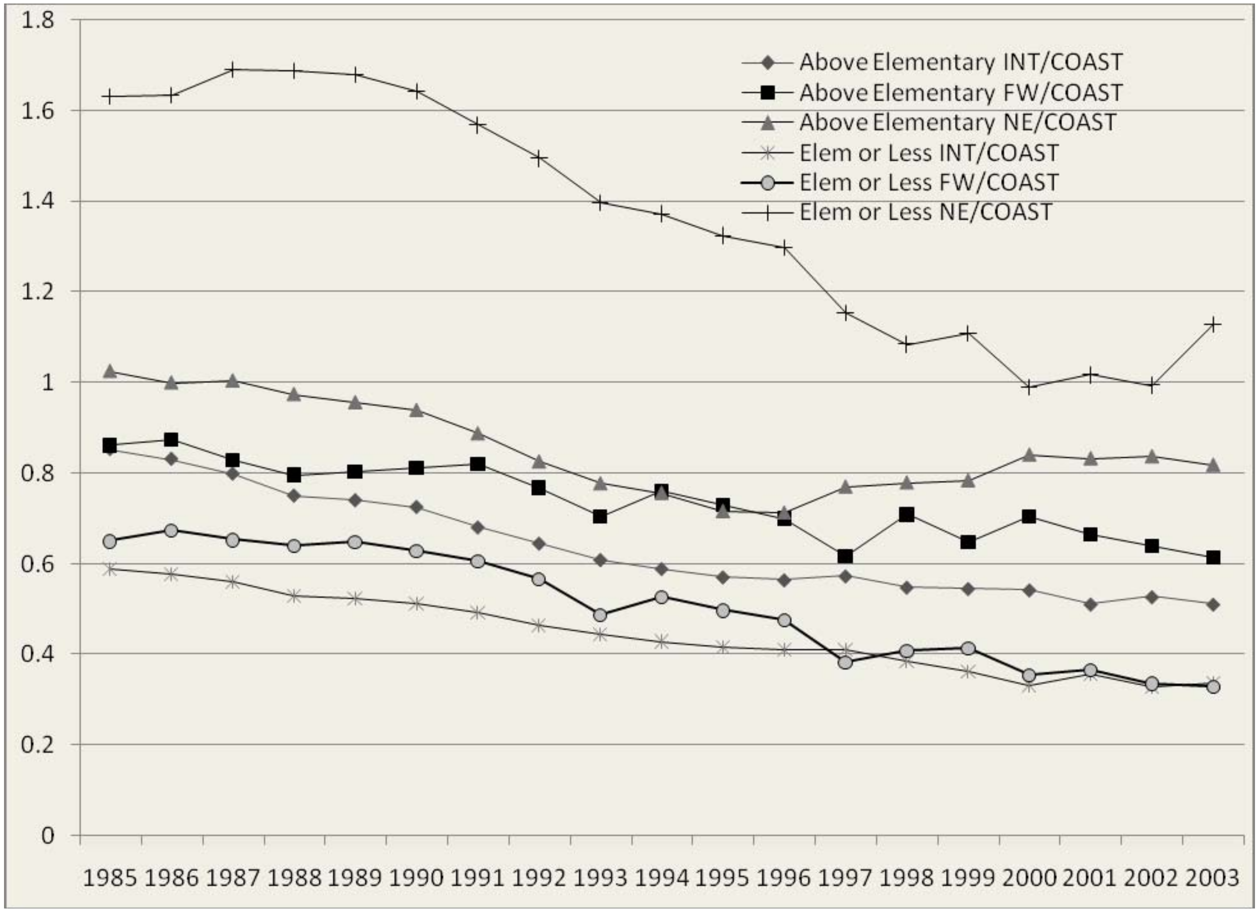
Figure 4 Number of Reported Xiagang Workers



Sources of data: various years of China labor statistical Yearbook

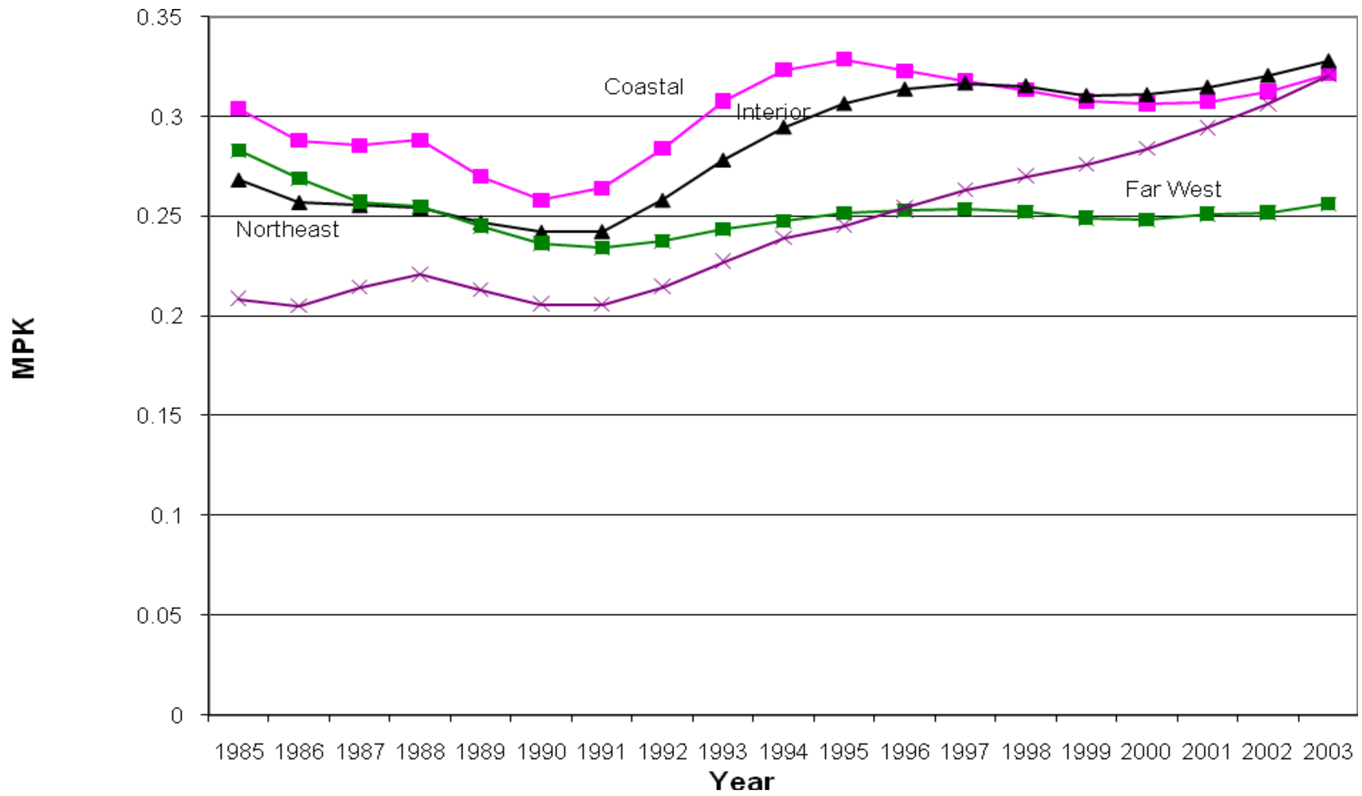
Figure 5 Marginal Product of Labor at Current Factor Quantities

Regional Ratios to Coast



Note: Marginal products are computed based on production function estimates shown in Table 3 (4), using mean year-specific regional factor quantities.

Figure 6 Marginal Product of Capital



Note: Marginal products are computed based on production function estimates shown in Table 3 (4), using mean year-specific regional factor quantities**.**

Appendix

Production Function:

$$\log Y_{i,t} = \log TFP_{i,t} + \beta_k \log K_{i,t} + \beta_e \log L_{ei,t} + \beta_n \log L_{ni,t} + u_{i,t}$$

TFP Growth Equation:

$$\begin{aligned}[\log TFP_{i,t} - \log TFP_{i,t-1}] &= \eta_{1,i} + \eta_{2,t} + \varphi_1 FDI_{i,t-2} + \varphi_2 FDI\_YB_{i,t-2} + \phi_1^h h_{i,t-1} + \\ &\phi_1^s h_{i,t-2}[\frac{1}{d_{\max\_i}}(\frac{y_{\max,t-2} - y_{i,t-2}}{y_{i,t-2}})] + \phi_2^s h_{i,t-2}[\frac{1}{d_{\max\_i}}(\frac{y_{\max,t-2} - y_{i,t-2}}{y_{i,t-2}})]\_YB + \\ &\phi_1^v \Delta_t^2 K_i + \beta^r Road_{i,t-2} + \beta^t Tel_{i,t-2} + \delta_1^m Mkt_{i,t-1} + \mu_{i,t}\end{aligned}$$

A. The Rate of Return to Education Based on Its Direct Contribution

Basic Assumptions:

- Policy scenario: each provincial government is going to launch an adult education program to move some of the workers from the low schooling (L_n) group to the high schooling (L_e) group. The goal of this exercise is to measure the rate of return to education based on its direct contribution on the production process.
- The future output in the absence of the adult education program is projected assuming all the variables stay constant (i.e., $L_{ei} = L_{ei,t+1} = L_{ei,t+2} = \ldots$ and $L_{ni} = L_{ni,t+1} = L_{ni,t+2} = \ldots$), so the annual growth of the future output is fixed to be w_i (t is set to be 2003).

$$w_i = \sum_{y=2000}^{2003} \log TFP_{i,y} - \log TFP_{i,y-1}$$

- After the completion of the adult education program, the workers would be sent to work for N_2 (=40) years (starting at time t+1).

$$dL_i = dL_{ei,t+1} = dL_{ei,t+2} = \ldots$$
$$= -dL_{ni,t+1} = -dL_{ni,t+2} = \ldots$$

Return to Education Based on Its Direct Contribution:

$\log Y_{i,t+j} - \log Y_{i,t+j-1} = w_i , \quad j \geq 1$

$\log Y_{i,t+j} = \log Y_{i,t} + j \cdot w_i$

Let $\Upsilon_{i,j} = j \cdot w_i$

Then, $Y_{i,t+j} = Y_{i,t} e^{\Upsilon_{i,j}}$

Return to education at time t+j:

$$\frac{\partial Y_{i,t+j}}{\partial L_{ei,t+j}} = \frac{Y_{i,t+j}}{L_{ei,t+j}} \beta_e = \frac{Y_{i,t} e^{\Upsilon_{i,j}}}{L_{ei}} \beta_e , \quad \frac{\partial Y_{i,t+j}}{\partial L_{ni,t+j}} = \frac{Y_{i,t+j}}{L_{ni,t+j}} \beta_n = \frac{Y_{i,t} e^{\Upsilon_{i,j}}}{L_{ni}} \beta_n$$

$$dY_{i,t+j} = \frac{Y_{i,t} e^{\Upsilon_{i,j}}}{L_{ei}} \beta_e dL_{ei,t+j} + \frac{Y_{i,t} e^{\Upsilon_{i,j}}}{L_{ni}} \beta_n dL_{ni,t+j} = \frac{Y_{i,t} e^{\Upsilon_{i,j}}}{L_{ei}} \beta_e dL_i - \frac{Y_{i,t} e^{\Upsilon_{i,j}}}{L_{ni}} \beta_n dL_i$$

Total return to education (from year t+1 to year t+N_2):

$$\text{Return} = (\frac{Y_{i,t}}{L_{ei}} \beta_e - \frac{Y_{i,t}}{L_{ni}} \beta_n) dL_i \cdot \sum_{j=1}^{N_2} \frac{e^{\Upsilon_{i,j}}}{(1+\rho_i^s)^j} , \quad \rho_i^s \text{ is the rate of return.}$$

Investment Cost:

The cost of investment per year:

Direct cost: D_i

Indirection cost: $\frac{\partial Y_{i,t}}{\partial L_{ni,t}} = \frac{Y_{i,t}}{L_{ni,t}} \beta_n$

Total cost: $dL_i \cdot (D_i + \frac{Y_{i,t}}{L_{ni}} \beta_n)$

Since L_e is defined as "above elementary school," we should maintain the same composition of the three education groups (namely lower middle school, upper middle school, and college) for computing the cost of the adult education program. The lengths of the lower middle school, the upper middle school, and the college educations are assumed to be three years, three years, and four years, respectively.

Let x_i, y_i, and z_i be the proportions of workers who have received lower middle school, upper middle school and college education in province *i* in 2003, respectively (note: x_i includes y_i, and y_i includes z_i). If there are dL_i number of workers who participate in the adult education program, then there will be $(y_i / x_i) \cdot dL_i$ number of the workers who will continue to upper middle school education, and $(z_i / x_i) \cdot dL_i$ number of the workers who will continue to college education in order to maintain the same composition of the three education groups.

Assume the costs of lower middle school, and upper middle school and college educations are $dL_i \cdot (D_i^l + \frac{Y_{i,t}}{L_{ni}} \beta_n)$, $dL_i \cdot (D_i^u + \frac{Y_{i,t}}{L_{ni}} \beta_n)$ and $dL_i \cdot (D_i^c + \frac{Y_{i,t}}{L_{ni}} \beta_n)$, respectively. The length of lower middle school education is N_l –year; the length of upper middle school education is N_u –year; the length of college education is N_c -year.

$$(1-\frac{y_i}{x_i})\cdot dL_i\cdot(D_i^l+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot[1+...+(\frac{1}{1+\rho_i^s})^{-N_l+1}]+$$

$$(\frac{y_i}{x_i}-\frac{z_i}{x_i})dL_i\cdot\{(D_i^u+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot[1+...+(\frac{1}{1+\rho_i^s})^{-N_u+1}]+\cdot(D_i^l+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot[(\frac{1}{1+\rho_i^s})^{-N_u}+...+(\frac{1}{1+\rho_i^s})^{-N_u-N_l+1}]\}+$$

$$\frac{z_i}{x_i}dL_i\cdot\{(D_i^c+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot[1+...+(\frac{1}{1+\rho_i^s})^{-N_c+1}]+(D_i^u+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot[(\frac{1}{1+\rho_i^s})^{-N_c}+...+(\frac{1}{1+\rho_i^s})^{-N_c-N_u+1}]+$$

$$(D_i^l+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot[(\frac{1}{1+\rho_i^s})^{-N_c-N_u}+...+(\frac{1}{1+\rho_i^s})^{-N_c-N_u-N_l+1}]\}$$

$$=(1-\frac{y_i}{x_i})\cdot dL_i\cdot(D_i^l+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot\frac{(1+\rho_i^s)^{N_l}-1}{\rho_i^s}+$$

$$(\frac{y_i}{x_i}-\frac{z_i}{x_i})dL_i\cdot\{(D_i^u+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot\frac{(1+\rho_i^s)^{N_u}-1}{\rho_i^s}+(D_i^l+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot\frac{(1+\rho_i^s)^{N_u+N_l}-(1+\rho_i^s)^{N_u}}{\rho_i^s}\}+$$

$$\frac{z_i}{x_i}dL_i\cdot\{(D_i^c+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot\frac{(1+\rho_i^s)^{N_c}-1}{\rho_i^s}+(D_i^u+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot\frac{(1+\rho_i^s)^{N_c+N_u}-(1+\rho_i^s)^{N_c}}{\rho_i^s}+$$

$$(D_i^l+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot\frac{(1+\rho_i^s)^{N_c+N_u+N_l}-(1+\rho_i^s)^{N_c+N_u}}{\rho_i^s}\}$$

The Rate of Return (ρ_i^s) to Education Based on Its Direct Contribution:

$$
\left(\frac{Y_{i,t}}{L_{ei}}\beta_e - \frac{Y_{i,t}}{L_{ni}}\beta_n\right)\sum_{j=1}^{N_2}\frac{e^{\Upsilon_{i,j}}}{(1+\rho_i^s)^j} = \left(1-\frac{y_i}{x_i}\right)\cdot\left(D_i^l + \frac{Y_{i,t}}{L_{ni}}\beta_n\right)\cdot\frac{(1+\rho_i^s)^{N_l}-1}{\rho_i^s} +
$$

$$
\left(\frac{y_i}{x_i}-\frac{z_i}{x_i}\right)\left\{\left(D_i^u + \frac{Y_{i,t}}{L_{ni}}\beta_n\right)\cdot\frac{(1+\rho_i^s)^{N_u}-1}{\rho_i^s} + \left(D_i^l + \frac{Y_{i,t}}{L_{ni}}\beta_n\right)\cdot\frac{(1+\rho_i^s)^{N_u+N_l}-(1+\rho_i^s)^{N_u}}{\rho_i^s}\right\} +
$$

$$
\frac{z_i}{x_i}\left\{\left(D_i^c + \frac{Y_{i,t}}{L_{ni}}\beta_n\right)\cdot\frac{(1+\rho_i^s)^{N_c}-1}{\rho_i^s} + \left(D_i^u + \frac{Y_{i,t}}{L_{ni}}\beta_n\right)\cdot\frac{(1+\rho_i^s)^{N_c+N_u}-(1+\rho_i^s)^{N_c}}{\rho_i^s} +\right.
$$

$$
\left.\left(D_i^l + \frac{Y_{i,t}}{L_{ni}}\beta_n\right)\cdot\frac{(1+\rho_i^s)^{N_c+N_u+N_l}-(1+\rho_i^s)^{N_c+N_u}}{\rho_i^s}\right\}
$$

B. The Rate of Return to Education Based on Its Indirect Contribution

Basic Assumptions:

- Policy scenario: each provincial government is going to launch an adult education program to raise the level of schooling achieved beyond the nine-year compulsory education requirement. To do this, some of the workers who are in the high schooling group (L_e) and haven't received beyond lower middle school education are randomly selected to obtain higher levels. The goal of this exercise is to measure the rate of return to education based on its indirect contribution through TFP growth on the production process.
- The future output in the absence of the adult education program is projected assuming all the variables stay constant (i.e., $L_{ei} = L_{ei,t+1} = L_{ei,t+2} = \ldots$; $L_{ni} = L_{ni,t+1} = L_{ni,t+2} = \ldots$; $Population_i = Population_{i,t+1} = Population_{i,t+2} = \ldots$), so the annual growth of the future output is fixed to be w_i (t is set to be 2003).

$$
w_i = \sum_{y=2000}^{2003} \log TFP_{i,y} - \log TFP_{i,y-1}
$$

- After the completion of the adult education program, the workers would be sent to work for N_2 years (starting at time t+1, with constant population $Population_i$).
- Let h_i and E_i denote the proportions of people and workers who have received education that is beyond the level of the nine-year compulsory education in province i, respectively.

$$Workforce_i \cdot dE_i = Population_i \cdot dh_i \quad \text{(True under our policy scenario)}$$
$$dE_i = dE_{i,t+1} = dE_{i,t+2} = \ldots,$$
$$dh_i = dh_{i,t+1} = dh_{i,t+2} = \ldots$$

Return to Education Based on Its Indirect Contribution:

$$y_{i,t+j} = \frac{Y_{i,t+j}}{Population_i} = \frac{Y_{i,t}e^{\Upsilon_{i,j}}}{Population_i}$$

Based on the TFP Growth Equation,

$$\log TFP_{i,t+2} = \log TFP_{i,t+1} + h_{i,t+1} \cdot \phi_1^h + h_{i,t} \cdot \phi_1^s [\frac{1}{d_{\max\_i}}(\frac{y_{\max,t} - y_{i,t}}{y_{i,t}})]\} + \ other \ \ variables$$

$$\log TFP_{i,t+3} = \log TFP_{i,t+2} + h_{i,t+2} \cdot \phi_1^h + h_{i,t+1} \cdot \phi_1^s [\frac{1}{d_{\max\_i}}(\frac{y_{\max,t+1} - y_{i,t+1}}{y_{i,t+1}})]\} + \ other \ \ variables$$
$$= \log TFP_{i,t+1} + h_{i,t+1} \cdot \phi_1^h + h_{i,t} \cdot \phi_1^s [\frac{1}{d_{\max\_i}}(\frac{y_{\max,t} - y_{i,t}}{y_{i,t}})]\} +$$
$$h_{i,t+2} \cdot \phi_1^h + h_{i,t+1} \cdot \phi_1^s [\frac{1}{d_{\max\_i}}(\frac{y_{\max,t+1} - y_{i,t+1}}{y_{i,t+1}})]\} + \ other \ \ variables$$

Let $\vartheta_{i,j} = \phi_1^h + \phi_1^s [\frac{1}{d_{\max\_i}}(\frac{y_{\max,t+j} - y_{i,t+j}}{y_{i,t+j}})]$

Note: Other variables are not the functions of *h*.

Return to education at time t+2: $Y_{i,t}e^{\Upsilon_{i,2}} \cdot \phi_1^h \cdot dh_i$

Return to education at time t+3: $Y_{i,t}e^{\Upsilon_{i,3}} \cdot (\phi_1^h + \vartheta_{i,1}) \cdot dh_i$

Return to education at time t+4: $Y_{i,t}e^{\Upsilon_{i,4}} \cdot (\phi_1^h + \vartheta_{i,1} + \vartheta_{i,2}) \cdot dh_i$

Total return to education (from year t+1 to year t+N_2, $N_2 \geq 2$):

$$\text{Return} = Y_{i,t} \cdot dh_i \cdot \sum_{j=2}^{N_2} \frac{(\phi_1^h + \sum_{k=1}^{j-2} \vartheta_{i,k}) \cdot e^{\Upsilon_{i,j}}}{(1+\rho_i^s)^j}$$

Investment Cost:

The cost of investment per year:

Direct cost: D_i

Indirection cost $\frac{dY_{i,t}}{dL_{ei,t}} = \frac{Y_{i,t}}{L_{ei,t}} \beta_e$

Total cost: $dE_i \cdot Workforce_i \cdot (\frac{Y_{i,t}}{L_{ei}} \beta_e + D_i)$

Since h_i is defined as the proportion of the people who have received education that is beyond the level the nine-year compulsory education, we should maintain the same composition of the two education groups (namely upper middle school and college) for computing the cost of the adult education program. The lengths of the upper middle school and the college educations are assumed to be three years and four years, respectively.

Let y_i, and z_i be the proportions of workers who have received upper middle school and college education in province i in 2003, respectively (note: y_i includes z_i). If there are dL_i number of workers who participate in the adult education program, then there will be $(z_i / y_i) \cdot dL_i$ number of workers who will continue to college education in order to maintain the same composition of the two education groups.

Assume the costs of upper middle school and college educations are $dE_i \cdot Workforce_i \cdot (D_i^u + \frac{Y_{i,t}}{L_{ei}}\beta_e)$ and $dE_i \cdot Workforce_i \cdot (D_i^c + \frac{Y_{i,t}}{L_{ei}}\beta_e)$, respectively. The length of upper middle school education is N_u –year, and the length of college education is N_c -year.

$$(1-\frac{z_i}{y_i})dE_i \cdot Workforce_i \cdot (\frac{Y_{i,t}}{L_{ei}}\beta_e + D_i^u)\cdot[1+(\frac{1}{1+\rho_i^s})^{-1}+\ldots+(\frac{1}{1+\rho_i^s})^{-N_u+1}]+$$
$$\frac{z_i}{y_i}dE_i \cdot Workforce_i \cdot \{(D_i^c + \frac{Y_{i,t}}{L_{ei}}\beta_e)\cdot[1+\ldots+(\frac{1}{1+\rho_i^s})^{-N_c+1}]+(D_i^u+\frac{Y_{i,t}}{L_{ei}}\beta_e)\cdot[(\frac{1}{1+\rho_i^s})^{-N_c}+\ldots+(\frac{1}{1+\rho_i^s})^{-N_c-N_u+1}]\}$$
$$=(1-\frac{z_i}{y_i})dE_i \cdot Workforce_i \cdot (\frac{Y_{i,t}}{L_{ei}}\beta_e + D_i^u)\cdot\frac{(1+\rho_i^s)^{N_u}-1}{\rho_i^s}+$$
$$\frac{z_i}{y_i}dE_i \cdot Workforce_i \cdot \{(D_i^c + \frac{Y_{i,t}}{L_{ei}}\beta_e)\cdot\frac{(1+\rho_i^s)^{N_c}-1}{\rho_i^s}+(D_i^u+\frac{Y_{i,t}}{L_{ei}}\beta_e)\cdot\frac{(1+\rho_i^s)^{N_c+N_u}-(1+\rho_i^s)^{N_c}}{\rho_i^s}\}$$

The Rate of Return (ρ_i^s) to Education Based on Its Indirect Contribution:

$$\frac{Y_{i,t}}{Population_i}\cdot\sum_{j=2}^{N_2}\frac{(\phi_1^h+\sum_{k=1}^{j-2}\vartheta_{i,k})\cdot e^{\Upsilon_{i,j}}}{(1+\rho_i^s)^j}=(1-\frac{z_i}{y_i})(\frac{Y_{i,t}}{L_{ei}}\beta_e + D_i^u)\cdot\frac{(1+\rho_i^s)^{N_u}-1}{\rho_i^s}+$$
$$\frac{z_i}{y_i}\{(D_i^c + \frac{Y_{i,t}}{L_{ei}}\beta_e)\cdot\frac{(1+\rho_i^s)^{N_c}-1}{\rho_i^s}+(D_i^u+\frac{Y_{i,t}}{L_{ei}}\beta_e)\cdot\frac{(1+\rho_i^s)^{N_c+N_u}-(1+\rho_i^s)^{N_c}}{\rho_i^s}\}$$

C. The Rate of Return to Education Based on Its Direct and Indirect Contribution

Basic Assumptions:

- Policy scenario: each provincial government is going to launch an adult education program to raise the level of schooling achieved beyond the nine-year compulsory education requirement. To do this, some of the workers who are in the low schooling group (L_n) are randomly selected to obtain higher education. The goal of this exercise is to measure the rate of return to education based on both its direct and indirect contributions on the production process.

- The future output in the absence of the adult education program is projected assuming all the variables stay constant (i.e., $L_{ei} = L_{ei,t+1} = L_{ei,t+2} = \ldots$; $L_{ni} = L_{ni,t+1} = L_{ni,t+2} = \ldots$; $Population_i = Population_{i,t+1} = Population_{i,t+2} = \ldots$), so the annual growth of the future output is fixed to be w_i (t is set to be 2003).

$$w_i = \sum_{y=2000}^{2003} \log TFP_{i,y} - \log TFP_{i,y-1}$$

- After the completion of the adult education program, the workers would be sent to work for N_2 years (starting at time t+1, with constant population $Population_i$).

$$dL_i = dL_{ei,t+1} = dL_{ei,t+2} = \ldots$$
$$= -dL_{ni,t+1} = -dL_{ni,t+2} = \ldots$$

- Let h_i and E_i denote the proportions of people and workers who have received education that is beyond the level of the nine-year compulsory education in province i, respectively.

$$dh_i = dL_i / Population_i \quad \text{(True under our policy scenario)}$$
$$dE_i = dE_{i,t+1} = dE_{i,t+2} = \ldots,$$
$$dh_i = dh_{i,t+1} = dh_{i,t+2} = \ldots$$

Return to Education Based on Its Direct Contribution:

$$\left(\frac{Y_{i,t}}{L_{ei}}\beta_e - \frac{Y_{i,t}}{L_{ni}}\beta_n\right)dL_i \cdot \sum_{j=1}^{N_2} \frac{e^{\Upsilon_{i,j}}}{(1+\rho_i^s)^j}$$

Return to Education Based on Its Indirect Contribution:

$$Y_{i,t} \cdot dh_i \cdot \sum_{j=2}^{N_2} \frac{(\phi_1^h + \sum_{k=1}^{j-2} \vartheta_{i,k}) \cdot e^{\Upsilon_{i,j}}}{(1+\rho_i^s)^j}$$

Investment Cost:

The cost of investment per year:

Direct cost: D_i

Indirection cost: $\dfrac{\partial Y_{i,t}}{\partial L_{ni,t}} = \dfrac{Y_{i,t}}{L_{ni,t}}\beta_n$

Total cost: $dL_i \cdot (D_i + \dfrac{Y_{i,t}}{L_{ni}}\beta_n)$

Since h_i is defined as the proportion of the people who have received education that is beyond the level the nine-year compulsory education, we should maintain the same composition of the two education groups (namely upper middle school and college) for computing the cost of the adult education program. The lengths of the lower middle school, the upper middle school, and the college educations are assumed to be three years, three years, and four years, respectively.

Let y_i, and z_i be the proportions of workers who have received upper middle school and college education in province i in 2003, respectively (note: y_i includes z_i). If there are dL_i number of workers who participate in the adult education program, then there will be $(z_i / y_i) \cdot dL_i$ number of workers who will continue to college education in order to maintain the same composition of the two education groups.

Assume the costs of lower middle school, and upper middle school and college educations are $dL_i \cdot (D_i^l + \dfrac{Y_{i,t}}{L_{ni}}\beta_n)$, $dL_i \cdot (D_i^u + \dfrac{Y_{i,t}}{L_{ni}}\beta_n)$ and $dL_i \cdot (D_i^c + \dfrac{Y_{i,t}}{L_{ni}}\beta_n)$, respectively. The length of lower middle school education is N_l –year; the length of upper middle school education is N_u –year; the length of college education is N_c -year.

$$(1-\frac{z_i}{y_i})dL_i\cdot\{(D_i^u+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot[1+...+(\frac{1}{1+\rho_i^s})^{-N_u+1}]+\cdot(D_i^l+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot[(\frac{1}{1+\rho_i^s})^{-N_u}+...+(\frac{1}{1+\rho_i^s})^{-N_u-N_l+1}]\}+$$

$$\frac{z_i}{y_i}dL_i\cdot\{(D_i^c+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot[1+...+(\frac{1}{1+\rho_i^s})^{-N_c+1}]+(D_i^u+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot[(\frac{1}{1+\rho_i^s})^{-N_c}+...+(\frac{1}{1+\rho_i^s})^{-N_c-N_u+1}]+$$

$$(D_i^l+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot[(\frac{1}{1+\rho_i^s})^{-N_c-N_u}+...+(\frac{1}{1+\rho_i^s})^{-N_c-N_u-N_l+1}]\}$$

$$=(1-\frac{z_i}{y_i})dL_i\cdot\{(D_i^u+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot\frac{(1+\rho_i^s)^{N_u}-1}{\rho_i^s}+(D_i^l+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot\frac{(1+\rho_i^s)^{N_u+N_l}-(1+\rho_i^s)^{N_u}}{\rho_i^s}\}+$$

$$\frac{z_i}{y_i}dL_i\cdot\{(D_i^c+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot\frac{(1+\rho_i^s)^{N_c}-1}{\rho_i^s}+(D_i^u+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot\frac{(1+\rho_i^s)^{N_c+N_u}-(1+\rho_i^s)^{N_c}}{\rho_i^s}+$$

$$(D_i^l+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot\frac{(1+\rho_i^s)^{N_c+N_u+N_l}-(1+\rho_i^s)^{N_c+N_u}}{\rho_i^s}\}$$

The Rate of Return (ρ_i^s) to Education Based on Both Its Direct and Indirect Contributions:

$$(\frac{Y_{i,t}}{L_{ei}}\beta_e-\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot\sum_{j=1}^{N_2}\frac{e^{\Upsilon_{i,j}}}{(1+\rho_i^s)^j}+\frac{Y_{i,t}}{Population_i}\cdot\sum_{j=2}^{N_2}\frac{(\phi_1^h+\sum_{k=1}^{j-2}\vartheta_{i,k})\cdot e^{\Upsilon_{i,j}}}{(1+\rho_i^s)^j}$$

$$=(1-\frac{z_i}{y_i})\cdot\{(D_i^u+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot\frac{(1+\rho_i^s)^{N_u}-1}{\rho_i^s}+(D_i^l+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot\frac{(1+\rho_i^s)^{N_u+N_l}-(1+\rho_i^s)^{N_u}}{\rho_i^s}\}+$$

$$\frac{z_i}{y_i}\cdot\{(D_i^c+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot\frac{(1+\rho_i^s)^{N_c}-1}{\rho_i^s}+(D_i^u+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot\frac{(1+\rho_i^s)^{N_c+N_u}-(1+\rho_i^s)^{N_c}}{\rho_i^s}+$$

$$(D_i^l+\frac{Y_{i,t}}{L_{ni}}\beta_n)\cdot\frac{(1+\rho_i^s)^{N_c+N_u+N_l}-(1+\rho_i^s)^{N_c+N_u}}{\rho_i^s}\}$$

The estimates of D (Direct Cost)

Direct cost = total expenditures/ total number of students

Unit: 100,000,000 yuan / 10,000 persons

Table I

Year: 2002	Higher Education	Upper Middle School	Lower Middle School
Beijing	2.8116	0.5149	0.3167
Tianjin	1.2546	0.3945	0.1367
Hebei	0.5967	0.1593	0.0623
Shanxi	0.6901	0.1753	0.0825
Inner Mongolia	0.6885	0.1491	0.0902
Liaoning	0.9439	0.2324	0.1012
Jilin	0.9738	0.2197	0.1037
Heilongjiang	0.8082	0.1367	0.0594
Shanghai	1.7431	0.4931	0.4075
Jiangsu	1.0842	0.3081	0.1235
Zhejiang	1.1719	0.3765	0.1904
Anhui	0.8645	0.1936	0.0710
Fujian	1.0761	0.2074	0.1072
Jiangxi	0.6734	0.1435	0.0677
Shandong	0.8363	0.2148	0.0891
Henan	0.5285	0.1157	0.0477

Hubei	1.0849	0.1880	0.0821
Hunan	0.8072	0.1850	0.0700
Guangxi	0.8064	0.1804	0.0883
Sichuan	1.0213	0.1776	0.0756
Guizhou	0.6730	0.1278	0.0530
Yunnan	0.7701	0.1881	0.0806
Shaanxi	0.9156	0.0936	0.0487
Gansu	0.8995	0.1421	0.0687
Qinghai	0.8827	0.1608	0.1028
Ningxia	0.8478	0.1394	0.0956
Xinjiang	0.6211	0.1664	0.1024
Guangdong	1.2340	0.2946	0.1231

Notes:
1. All the data were collected from the 2003 Education Statistical Yearbook and the 2003 China Statistical Year Book.
2. The total expenditure data are deflated using GDP deflator (base = Beijing, 1990).
3. Hainan is included in Guangdong; Chongqing is included in Sichuan.

D. The Rate of Return to Infrastructure Investment

Basic Assumptions:

- Policy scenario: each provincial government is going to invest *C* dollars on infrastructure at time t. The goal of this exercise is to measure the rate of return to infrastructure investment.
- The newly increased infrastructure would be available at the beginning of time t+1. The rate of return is computed based on the service provided by the newly increased infrastructure during the time period between t+1 and t+N_2.
- The future output in the absence of the adult education program is projected assuming all the variables stay constant, so the annual growth of the future output is fixed to be w_i (t is set to be 2003).

$$w_i = \sum_{y=2000}^{2003} \log TFP_{i,y} - \log TFP_{i,y-1}$$

- The depreciation rate (R) is set to 0.06. The initial stock of infrastructure (at time t) is assumed to be fixed at the same level throughout the years. The depreciation is applied only to the newly increased infrastructure (starting at t+2).

$$dTel_{i,t+j} = (1-R)^{j-1} dTel_i, \quad j \geq 2$$

$$dRoad_{i,t+j} = (1-R)^{j-1} dRoad_i, \quad j \geq 2$$

Telephone Infrastructure

Based on the TFP Growth Equation,

$$\log TFP_{i,t+3} = \log TFP_{i,t+2} + \beta^t Tel_{i,t+1} + \ other \ \ variables$$

Note: Other variables are not the functions of *Tel*.

Return to telephone infrastructure at time t+3:

$$dY_{i,t+3} = Y_{i,t} e^{\Upsilon_{i,3}} \cdot \beta^t \cdot dTel_{i,t+1} = Y_{i,t} e^{\Upsilon_{i,3}} \cdot \beta^t \cdot dTel_i$$

Return to telephone infrastructure at time t+4:

$$dY_{i,t+4} = Y_{i,t} e^{\Upsilon_{i,4}} \cdot \beta^t \cdot [1+(1-R)] \cdot dTel_i$$

Return to Road Construction at time t+j ($j \geq 3$):

$$dY_{i,t+j} = Y_{i,t} e^{\Upsilon_{i,j}} \cdot \beta^t \cdot \frac{1-(1-R)^{j-2}}{R} \cdot dTel_i$$

Total return to road (from year t+1 to year t+N_2):

$$\text{Return} = Y_{i,t} \cdot \beta^t \cdot dTel_i \cdot \sum_{j=3}^{N_2} \frac{e^{\Upsilon_{i,j}}}{(1+\rho_i^s)^j} \cdot \frac{1-(1-R)^{j-2}}{R}$$

Investment Cost:

Let C_i^t be the unit cost of telephone in Province *i*.

Then, the investment cost is: $dTel_i \cdot Population_i \cdot C_i^t$

The Rate of Return (ρ_i^s) to Telephone Infrastructure:

$$Y_{i,t} \cdot \beta_1^t \cdot \sum_{j=3}^{N_2} \frac{e^{\Upsilon_{i,j}}}{(1+\rho_i^s)^j} \cdot \frac{1-(1-R)^{j-2}}{R} = Population_i \cdot C_i^t$$

Cost estimates for the telephone

The China Statistical Yearbook reports the aggregate investment in "Transportation, Storage, Postal and Telecommunication Services." There is no simple way to separate telecommunication investment from transportation investment. In order to estimate the cost of telecommunication, we run a simple regression model with the dependent variable defined as the average annual investment in transportation, storage, postal and telecommunication services between 2001 and 2002 (per 100 million yuan). The independent variables are (the data on storage facility are not available) as follows:

avg_road_01_02: average annual road construction between 2001 and 2002 (per 1,000 km).

avg_telephone_01_02: average annual number of urban telephone subscribers increased between 2001 and 2002 (per 10,000 unit).

In this exercise, we estimate the marginal cost of telecommunication infrastructure, using telephone ownership as a proxy for such infrastructure. We assume that the average cost is constant and thus equals to the marginal cost. The regression results are reported in Table II below. All the monetary values were deflated using the price index of investment (Base = Beijing, 1990)

Table II

Regressor	Coefficient	Std Error	t-statistc	p-value
Intercept	21.24	13.04	1.63	0.12

avg_road_01_02	0.27	1.02	0.26	0.79
avg_telephone_01_02	1.10	0.14	8.02	<.0001
Adjusted R-square: 0.7003				

Notes:
1. Hainan is included in Guangdong; and Chongqing is included in Sichuan. Tibet and Inner Mongolia are excluded for lack of continuous data.
2. We would like to use more recent data to estimate the costs for road construction and telephone. However, the telecommunication services are no longer grouped with transportation, storage and postal since 2003.

E. Impact on Regional Ratios of Per-Capita GDP under Alternative Hypothetical Policy Scenarios in 2013

Basic Assumptions:

- Policy scenario: the central government is going to invest in human capital or telecommunication infrastructure in the northeast, far west and interior regions, in order to reduce the regional per-capita output gaps.
- There are five phases in this investment project. In each phase, the central government would distribute 10% of their annual revenue to the non-coastal provinces (weighed by their population size) to carry out the investment project.[41]
- The first phase of the investment project would be completed at the beginning of 2004, and the last phase investment project would be completed at the beginning of 2008. The impacts of those investment projects on regional inequality are evaluated at the end of the 10th year (2013).
- There are two channels through which human capital can impact on output: the direct contribution to the production process and the indirect contribution through the TFP growth on the production process. For the direct contribution, each non-coastal provincial government would launch an adult education program to move some of the workers from the low-skilled (L_n) group to the high-skilled (L_e) group. For the indirect contribution, each non-coastal provincial government would launch an adult education program to provide education service, which is beyond the level of the nine-year compulsory education, to some of

[41] The total government revenue is 2171.525 billion yuan in 2003. We assume that the central government would spend 217.1525 billion yuan in each phase of the investment project. For simplicity, we also assume that the unit costs of human capital and telecommunication infrastructure stay the same throughout the investment project, and the calculations of the unit costs are provided in Appendix A-D.

the workers. The lengths of the lower middle school, upper middle school and college education are assumed to be 3-year, 3-year and 4-year, respectively.

- The depreciation rate of the telecommunication infrastructure (R) is assumed to be 0.06. The initial stock of the infrastructure (in 2003) is assumed to be fixed at the same level throughout the years. The depreciation is applied only to the newly increased infrastructure (starting at the beginning of 2005).
- We assume $\log Y_{i,t+1} - \log Y_{i,t} = \log TFP_{i,t+1} - \log TFP_{i,t} = w_i$ in projecting the "future" output and TFP in the absence of the investment project. w_i is a provincial-specific constant ($w_i = \sum_{y=2000}^{2003} \log TFP_{i,y} - \log TFP_{i,y-1}$). For simplicity, we assume that $\frac{y_{\max} - y_i}{y_i}$ stays constant at the 2003 level throughout the years.

Direct Contribution of Human Capital:

Let g_i be the increase in the number of high-skilled workers (L_e) in each phase of the investment project.

t = 2004: $L_{ei} \rightarrow L_{ei} + g_i \qquad L_{ni} \rightarrow L_{ni} - 5 \cdot g_i$

$\vdots$

t ≥ 2008: $L_{ei} \rightarrow L_{ei} + 5 \cdot g_i \qquad L_{ni} \rightarrow L_{ni} - 5 \cdot g_i$

$$\log Y_{i,2004}^{New} - \log Y_{i,2003} = w_i + \beta_e \cdot \log(\frac{L_{ei} + g_i}{L_{ei}}) + \beta_n \cdot \log(\frac{L_{ni} - 5 \cdot g_i}{L_{ni}})$$

$\vdots$

$$\log Y_{i,2008}^{New} - \log Y_{i,2007}^{New} = w_i + \beta_e \cdot \log(\frac{L_{ei} + 5 \cdot g_i}{L_{ei} + 4 \cdot g_i})$$

$$\log Y_{i,2009}^{New} - \log Y_{i,2008}^{New} = w_i$$

$\vdots$

$$\log Y_{i,2013}^{New} - \log Y_{i,2003} = 10 \cdot w_i + \beta_e \cdot \sum_{t=1}^{5} \log(\frac{L_{ei} + t \cdot g_i}{L_{ei} + (t-1) \cdot g_i}) + \beta_n \cdot \log(\frac{L_{ni} - 5 \cdot g_i}{L_{ni}})$$

$$\Rightarrow Y_{i,2013}^{New} = Y_{i,2003} \cdot \exp\left(10 \cdot w_i + \beta_e \cdot \log(\frac{L_{ei} + 5 \cdot g_i}{L_{ei}}) + \beta_n \cdot \log(\frac{L_{ni} - 5 \cdot g_i}{L_{ni}})\right)$$

Indirect Contribution of Human Capital:
Let g_i be the number of workers who are involved in the adult education program in each phase of the investment project. The first phase of the investment project is completed at the beginning of 2004, but the growth rate of *TFP* would not be affected until in 2005 due to the assumption of the lagged impact. Let L_{ci} denote the original number of workers who have received education that is beyond the level of the nine-year compulsory education.

t = 2004: $L_{ei} \rightarrow L_{ei} - 4 \cdot g_i$ $\quad L_{ci} \rightarrow L_{ci} + g_i$

t = 2005: $L_{ei} \rightarrow L_{ei} - 3 \cdot g_i$ $\quad L_{ci} \rightarrow L_{ci} + 2 \cdot g_i$

⋮

t ≥ 2008: $L_{ei} \rightarrow L_{ei}$ $\quad L_{ci} \rightarrow L_{ci} + 5 \cdot g_i$

$$\log Y_{i,2004}^{New} - \log Y_{i,2003} = w_i + \beta_e \cdot \log(\frac{L_{ei} - 4 \cdot g_i}{L_{ei}})$$

$$\log Y_{i,2005}^{New} - \log Y_{i,2004}^{New} = w_i + \beta_e \cdot \log(\frac{L_{ei} - 3 \cdot g_i}{L_{ei} - 4 \cdot g_i}) + \frac{g_i \phi_1^h}{populaton_i}$$

$$\log Y_{i,2006}^{New} - \log Y_{i,2005}^{New} = w_i + \beta_e \cdot \log(\frac{L_{ei} - 2 \cdot g_i}{L_{ei} - 3 \cdot g_i}) + (2\phi_1^h + \phi_1^s[\frac{1}{d_{\max\_i}}(\frac{y_{\max} - y_i}{y_i})])\frac{g_i}{populaton_i}$$

⋮

$$\log Y_{i,2008}^{New} - \log Y_{i,2007}^{New} = w_i + \beta_e \cdot \log(\frac{L_{ei}}{L_{ei} - g_i}) + \left(4\phi_1^h + 3\phi_1^s[\frac{1}{d_{\max\_i}}(\frac{y_{\max} - y_i}{y_i})]\right) \cdot \frac{g_i}{populaton_i}$$

$$\log Y_{i,2009}^{New} - \log Y_{i,2008}^{New} = w_i + \left(5\phi_1^h + 4\phi_1^s[\frac{1}{d_{\max\_i}}(\frac{y_{\max} - y_i}{y_i})]\right) \cdot \frac{g_i}{population_i}$$

$$\log Y_{i,2010}^{New} - \log Y_{i,2009}^{New} = w_i + \left(\phi_1^h + \phi_1^s [\frac{1}{d_{\max\_i}} (\frac{y_{\max} - y_i}{y_i})] \right) \cdot \frac{5 \cdot g_i}{population_i}$$

$\vdots$

$$\log Y_{i,2013}^{New} - \log Y_{i,2003} = 10 \cdot w_i + \left(35\phi_1^h + 30\phi_1^s [\frac{1}{d_{\max\_i}} (\frac{y_{\max} - y_i}{y_i})] \right) \cdot \left(\frac{g_i}{population_i} \right)$$

$$\Rightarrow Y_{i,2013}^{New} = Y_{i,2003} \cdot \exp\left(10 \cdot w_i + \left(35\phi_1^h + 30\phi_1^s [\frac{1}{d_{\max\_i}} (\frac{y_{\max} - y_i}{y_i})] \right) \cdot \left(\frac{g_i}{population_i} \right) \right)$$

Both Direct and Indirect Contributions of Human Capital:

t = 2004: $L_{ni} \rightarrow L_{ni} - 5 \cdot g_i \quad L_{ei} \rightarrow L_{ei} + g_i \quad L_{ci} \rightarrow L_{ci} + g_i$

t = 2005: $L_{ni} \rightarrow L_{ni} - 5 \cdot g_i \quad L_{ei} \rightarrow L_{ei} + 2 \cdot g_i \quad L_{ci} \rightarrow L_{ci} + 2 \cdot g_i$

$\vdots$

t ≥ 2008: $L_{ni} \rightarrow L_{ni} - 5 \cdot g_i \quad L_{ei} \rightarrow L_{ei} + 5 \cdot g_i \quad L_{ci} \rightarrow L_{ci} + 5 \cdot g_i$

$$\log Y_{i,2004}^{New} - \log Y_{i,2003} = w_i + \beta_e \cdot \log(\frac{L_{ei} + g_i}{L_{ei}}) + \beta_n \cdot \log(\frac{L_{ni} - 5 \cdot g_i}{L_{ni}})$$

$$\log Y_{i,2005}^{New} - \log Y_{i,2004}^{New} = w_i + \beta_e \cdot \log(\frac{L_{ei} + 2 \cdot g_i}{L_{ei} + g_i}) + \frac{\phi_1^h g_i}{populaton_i}$$

$\vdots$

$$\log Y_{i,2008}^{New} - \log Y_{i,2007}^{New} = w_i + \beta_e \cdot \log(\frac{L_{ei} + 5 \cdot g_i}{L_{ei} + 4 \cdot g_i}) + \left(4\phi_1^h + 3\phi_1^s [\frac{1}{d_{\max\_i}} (\frac{y_{\max} - y_i}{y_i})] \right) \cdot \frac{g_i}{populaton_i}$$

$$\log Y_{i,2009}^{New} - \log Y_{i,2008}^{New} = w_i + \left(5\phi_1^h + 4\phi_1^s [\frac{1}{d_{\max\_i}} (\frac{y_{\max} - y_i}{y_i})] \right) \cdot \frac{g_i}{population_i}$$

$$\log Y_{i,2013}^{New} - \log Y_{i,2003} = 10 \cdot w_i + \beta_e \cdot \log(\frac{L_{ei} + 5 \cdot g_i}{L_{ei}}) + \beta_n \cdot \log(\frac{L_{ni} - 5 \cdot g_i}{L_{ni}}) +$$

$$\left(35\phi_1^h + 30\phi_1^s [\frac{1}{d_{\max\_i}} (\frac{y_{\max} - y_i}{y_i})] \right) \cdot \left(\frac{g_i}{population_i} \right)$$

$$\log Y_{i,2013}^{New} = Y_{i,2003} \cdot \exp \left(\begin{array}{l} 10 \cdot w_i + \beta_e \cdot \log(\frac{L_{ei} + 5 \cdot g_i}{L_{ei}}) + \beta_n \cdot \log(\frac{L_{ni} - 5 \cdot g_i}{L_{ni}}) + \\ \left(35\phi_1^h + 30\phi_1^s [\frac{1}{d_{\max\_i}} (\frac{y_{\max} - y_i}{y_i})] \right) \cdot \left(\frac{g_i}{population_i} \right) \end{array} \right)$$

Telecommunication Infrastructure:

Let g_i be the increase in the telecommunication infrastructure in each phase of the investment project. The first phase of the investment project is completed at the beginning of 2004, but the growth rate of *TFP* will not be affected until in 2006 due to the assumption of the lagged impact.

t = 2004: $Tel_i \rightarrow Tel_i + g_i$

t = 2005: $Tel_i \rightarrow Tel_i + 2 \cdot g_i$

⋮

t ≥ 2008: $Tel_i \rightarrow Tel_i + 5 \cdot g_i$

$$\log Y_{i,2006}^{New} - \log Y_{i,2005} = w_i + \beta^t \frac{g_i}{Population_i}$$

⋮

$$\log Y_{i,2010}^{New} - \log Y_{i,2009}^{New} = w_i + \beta^t \frac{g_i + g_i \cdot (1-R) + g_i \cdot (1-R)^2 + g_i \cdot (1-R)^3 + g_i \cdot (1-R)^4}{Population_i}$$

$$\log Y_{i,2011}^{New} - \log Y_{i,2010}^{New} = w_i + \beta^t \frac{g_i + g_i \cdot (1-R) + g_i \cdot (1-R)^2 + g_i \cdot (1-R)^3 + g_i \cdot (1-R)^4}{Population_i} \cdot (1-R)$$

$$\vdots$$

Let $q = 1 + (1-R) + (1-R)^2 + (1-R)^3 + (1-R)^4 = \dfrac{1-(1-R)^5}{R}$

Denote z as follows:

$$z = 5 + 4(1-R) \ \ + 3(1-R)^2 + 2(1-R)^3 + (1-R)^4 + q(1-R) + q(1-R)^2 + q(1-R)^3$$

$$Y_{i,2013}^{New} = Y_{i,2003} \exp\left(\frac{\beta^t}{Population_i} g_i \cdot z + 10 \cdot w_i \right)$$